# CONCEPTS OF SCIENCE

# 2

R. G. Cull W. A. Drake

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## 2

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# Preface

*Concepts of Science 2* continues the introductory course provided in *Concepts of Science 1* for students in Year 7. The sequence of topics in this book has been chosen to provide a developing course for students of secondary science in Year 8.

The arrangement of experiments, questions and test in each chapter is the same as in *Concepts of Science 1*. The questions that require further research by the student are marked (R).

R. G. C.
W. A. D.

# Acknowledgments

The authors wish to acknowledge and thank those people who assisted in the preparation of this book. In particular, they would like to thank I. Plimer of Macquarie University for much valuable help in the preparation of the geology chapters, A. Torrens for his painstaking work in producing many of the photographs, and, especially, Barbara Gurney who prepared the illustrations.

# 1

# Star trails

Anyone watching the stars soon notices that their positions in the sky change during the course of the evening. The observer sees that the stars are apparently moving.

## Apparent movement of stars

*Stars rise in the east.* Looking towards the east soon after sunset, note the position of any one star against some feature of the horizon such as a house or a tree. Observe this star at half-hour intervals for the next two hours. You will notice that the star is rising above the horizon.

A camera may be used to verify this observation. By fixing the camera in one position pointing towards the east and leaving the shutter open for an hour or so, a photo similar to the one shown in figure 1.1 will be obtained. Notice that the stars are not rising vertically from the horizon but along a path that is tilted towards the north.

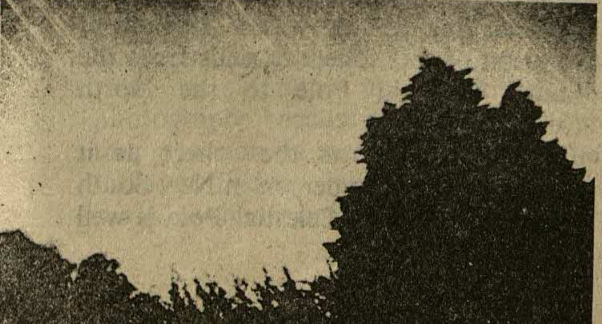


**Figure 1.1:** Star trails in the east. Notice that the trails are inclined towards the left, that is, the north. (Photo taken near Sydney, New South Wales.)

It is important to note that figure 1.1 and the following four photographs were taken near Sydney, New South Wales.

*Stars set in the west.* Figure 1.2 is a time exposure of Orion setting in the west. Here again you will notice that the trails are inclined towards the north.

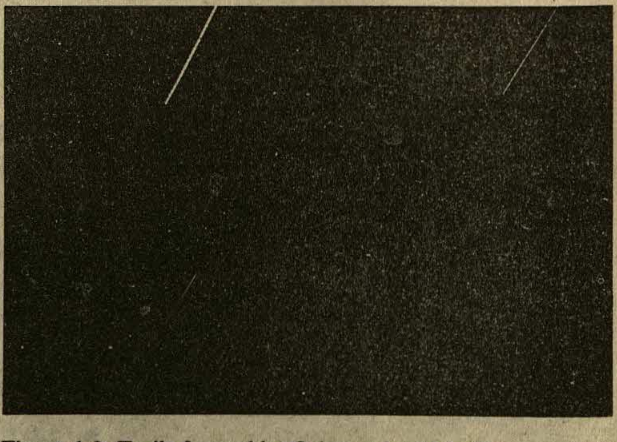


**Figure 1.2:** Trails formed by Orion as it sets in the west. Notice that the trails are inclined towards the north.

*Movement of stars overhead.* Figure 1.3 is a time exposure taken with the camera pointing approximately vertically overhead.

*Movement of stars in the south.* Figure 1.4 shows that the stars in the south move in paths that appear to be arcs of circles that have a common centre. The centre of all these circles is the South Celestial Pole.

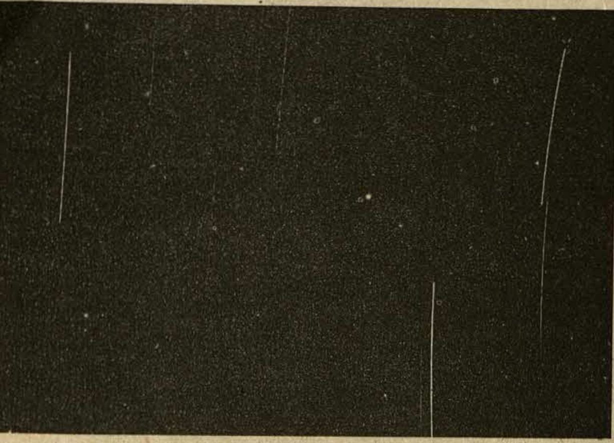
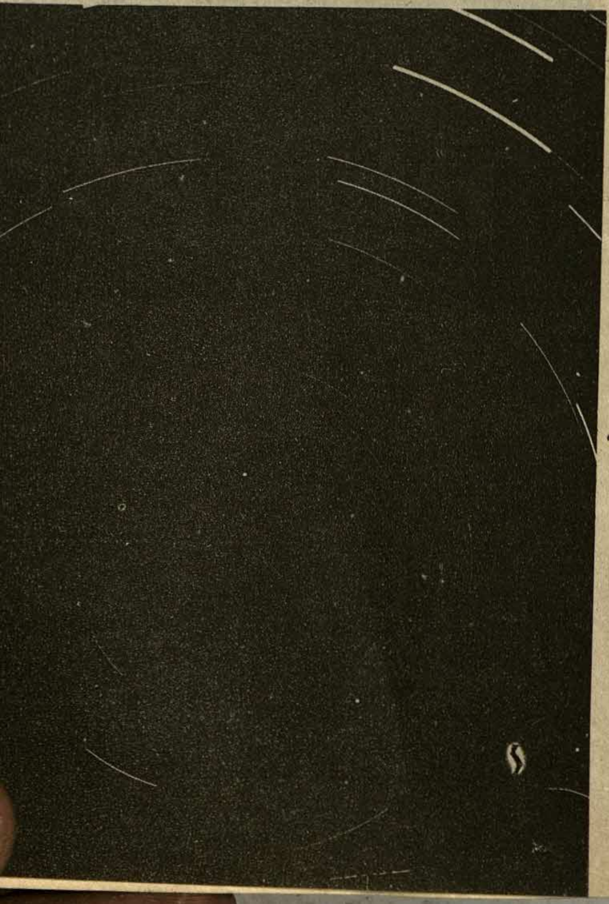


Figure 1.3: Star trails overhead. This photograph is a time exposure of Orion and was taken with the camera pointed a little to the north of directly overhead.

Figure 1.4: Star trails in the south. They seem to be arcs of circles. The common centre of these circles is the South Celestial Pole.



***Movement of stars in the north.*** Figure 1.5 shows that the paths travelled by the stars in the north form arcs above the horizon. The centre of these arcs is apparently below the horizon. The North Celestial Pole cannot be seen by observers in Australia. For them it is below the horizon in the same way that the South Celestial Pole is below the southern horizon for observers in the northern hemisphere.

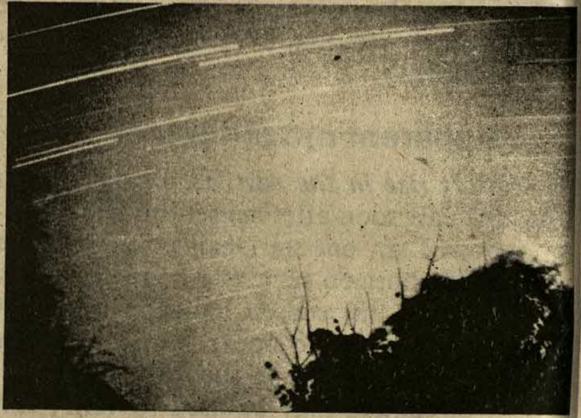


Figure 1.5: Star trails in the north. The centre of these arcs is well below the horizon.

## The celestial sphere

To explain the nightly movement of the stars, we use a model called the *celestial sphere*. As we watch the stars at night we think of ourselves as being at the centre of a huge hollow ball or sphere. The stars are on the surface of this sphere. During the course of the evening we imagine that this huge sphere is slowly turning, carrying the stars with it. The axis of rotation of this sphere extends from the South Celestial Pole to the North Celestial Pole.

Figure 1.6 shows the sphere as it would appear to a person in New South Wales. The South Celestial Pole is well

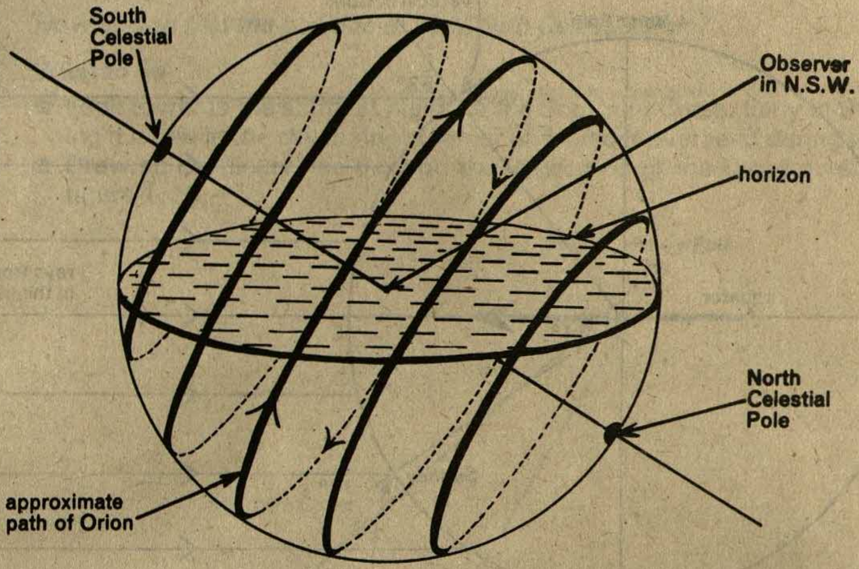


**Figure 1.6:** The celestial sphere as it would appear to an observer in New South Wales.

above the horizon while the North Celestial Pole is below the horizon. The paths of the stars are tilted towards the north.

## Are the stars really moving?

It is easy to understand how the early astronomers came to think that the earth was the centre of the universe. All the heavenly bodies — the stars, the sun, the planets and the moon — move across the sky in the one general direction. They all seem to revolve around the earth.

In the next chapter we will discuss the evidence against this idea — evidence that indicates it is the earth that is moving and not the heavens around it. In the meantime, however, we shall examine star trails more closely. Would you agree that stars show up as trails in photographs because the camera rather than the stars is moving? Why are the trails at Sydney inclined towards the north, as shown in figure 1.1?

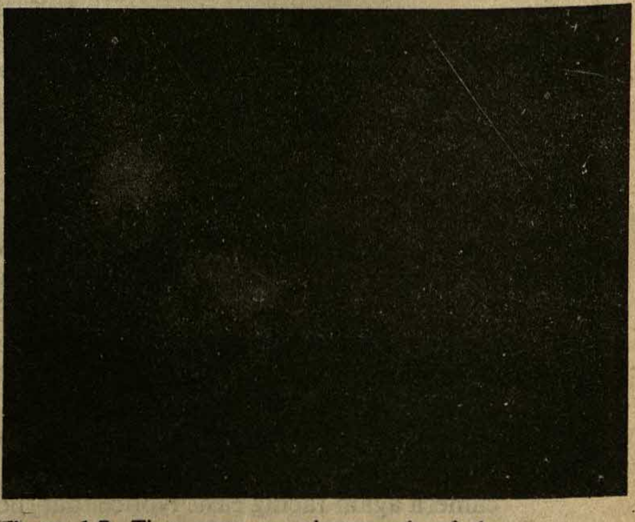


**Figure 1.7:** Time exposure photograph of the eastern sky at Sydney. The pole is included to show the inclination of the star trails to the vertical.

Let us examine the photograph in figure 1.7. It is another photograph of the east taken near Sydney. In this one, however, a pole was deliberately included to give us a vertical line in this pic-

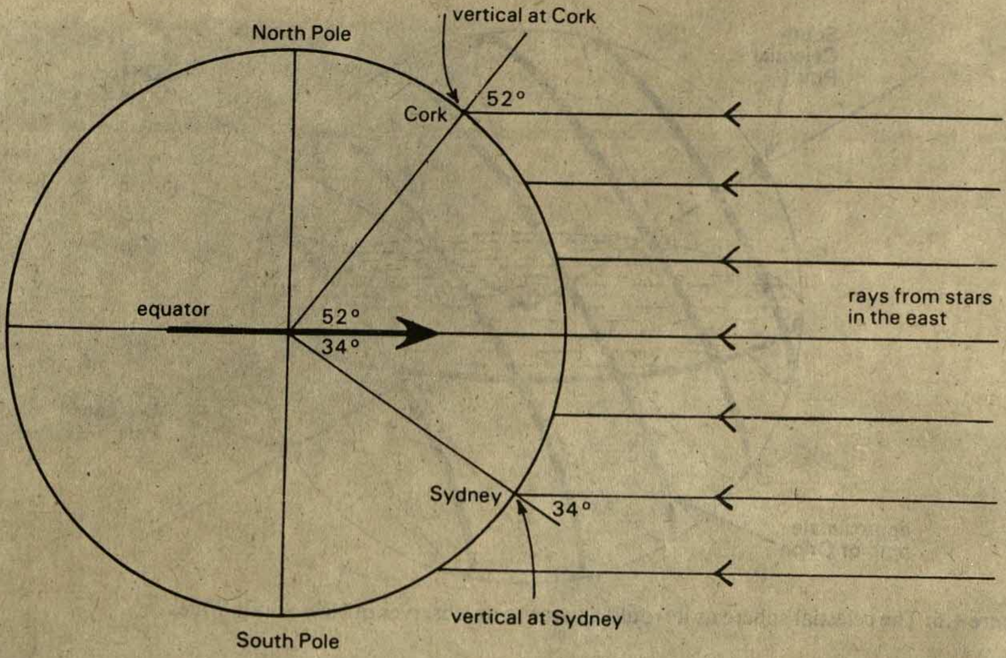


**Figure 1.8:** The earth rotates from west to east. This is why the sun and other stars appear to rise in the east and set in the west. To a person at the equator, the stars appear to rise vertically from below the horizon. To a person south or north of the equator, the stars appear to rise at an angle to the vertical. At Sydney this angle is 34°, which is the latitude of Sydney.

ture. If we measure the angles between the trails and the vertical, we find them to be about 35°. What is this angle of 35°? It is very close to the latitude angle of Sydney, which is 34°. Sydney is 34° south of the equator. (See figure 1.8.)

Now look at figure 1.9. This photo was taken at Cork, in Ireland, with the camera again facing east. Notice that the trails are sloping in the opposite direction to those at Sydney, that is, to the south. If we measure the angle these trails make with the vertical, we find it to be 52°. This is the latitude of Cork.

You can now see we have a simple way of finding how far north or south of the equator a place is. Look again at figure 1.9.

**Figure 1.9:** Time exposure photograph of the eastern sky taken at Cork, in Ireland. The latitude of Cork is 52° north.

**EXPERIMENT 1.1**

### *How do you find the position of the South Celestial Pole?*

**What to do**

- Look towards the south at night for the Southern Cross. Early in the evening it is low in the sky during summer and almost overhead during winter.
- Draw an imaginary line through the larger axis of the Cross as shown in figure 1.10.

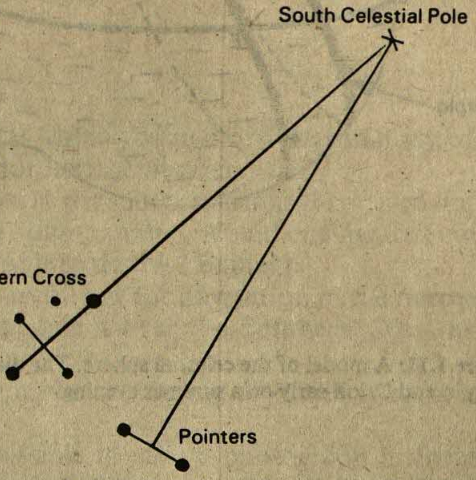


**Figure 1.10:** Finding the South Celestial Pole. This drawing shows the Southern Cross and the Pointers placed as they are in early evening at the end of March.

- Imagine a line joining the two Pointers. Bisect this line at right angles. Extend the bisector until it meets the line drawn through the Cross. The intersection is the South Celestial Pole.
- To find true south, drop an imaginary line vertically downwards from the South Celestial Pole.

**EXPERIMENT 1.2**

### *To show star trails on a model*

**Each group will need:**

- 500 mL round-bottomed flask, preferably with a long neck
- stopper
- felt pen
- 30° set square

**What to do**

- Mark circles on the flask to represent the paths of Orion, Scorpio and the Southern Cross. (See figure 1.11.) Do this by supporting your felt pen on one or more exercise books according to the path to be drawn. Hold the flask vertically on the bench and rotate it against the felt pen so that a circle is made on the glass at the height required for that particular constellation.

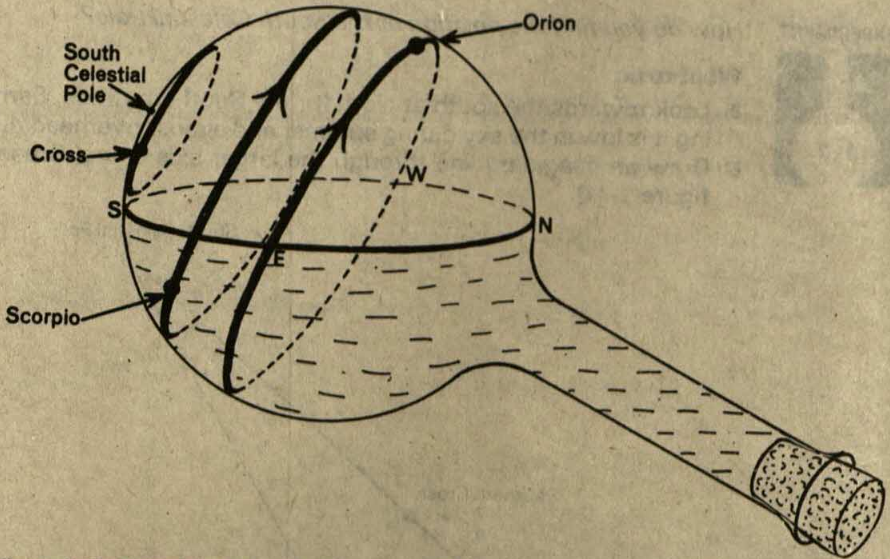


**Figure 1.11:** A model of the celestial sphere. The diagram shows the positions of the Cross, Scorpio and Orion early on a summer evening.

- Half fill the flask with water and fit the stopper.
- Hold the flask so that the neck is inclined at about 30° to the horizontal. Rotate the flask to show how the stars appear to move at night.

**Questions**

**1.1** Does the Southern Cross go below the horizon at night in Sydney?
**1.2** Why cannot Scorpio and Orion both be seen on the same night?
**1.3** How would the Southern Cross appear to move to a watcher at the equator?
**1.4** Do people in England see Orion, Scorpio and the Southern Cross? Explain.

## Star trails

1. The stars appear to move across the sky during the night.
2. To observers in the southern hemisphere:
   - The stars in the south move clockwise around a point called the South Celestial Pole.
   - The stars in the north move in arcs across the horizon from east to west.
3. The celestial sphere is a model that helps to explain the apparent movement of the stars.

## Spelling list

axis
bisector
celestial
exposure
hemisphere
latitude
revolve
rotate
rotation
sphere
trail

## More questions

**1.5** What alterations would you make to the summary of this chapter for readers in the northern hemisphere?

**1.6** Early navigators in the southern hemisphere used the Southern Cross for indicating due south. Would navigators in the northern hemisphere be able to do this? Explain.

**1.7** What star is a useful aid for navigation in the northern hemisphere? What advantage has it over the Southern Cross as a direction indicator? (R)

**1.8** Are there stars in the sky during daytime? If so, is it possible to see them? (R)

**1.9** Would it be possible to take a photograph in Sydney showing the trail of one particular star as a full circle by pointing the camera towards the South Celestial Pole? Explain. (See appendix 1.)

**1.10** How do stars in the east appear to move to a person at the equator?

**1.11** Suppose a person at the equator took a photo of star trails with the camera pointed to the south. What would the photo look like? Draw a diagram.

**1.12** How do the stars appear to move to a person stationed at the South Pole?

## Test yourself (chapter 1)

Choose the best answer to each question and write its letter in your workbook.

1. The Southern Cross at night
   (a) is always due south
   (b) rotates about a point in the sky that is due south
   (c) rotates about a point in the sky that is directly above due south
   (d) is at the South Celestial Pole.
2. A person at a particular place notices that the stars due east rise vertically above the horizon. The particular place must be
   (a) at the North Pole
   (b) at the equator
   (c) at a position half way between the equator and the South Pole
   (d) at the South Pole.

3. A photographer points his camera at the South Celestial Pole and takes a time exposure of star trails. His photograph looks like figure 1.12. To take this picture, the film must have been exposed for
   (a) 1 hour
   (b) 6 hours
   (c) 9 hours
   (d) 12 hours.

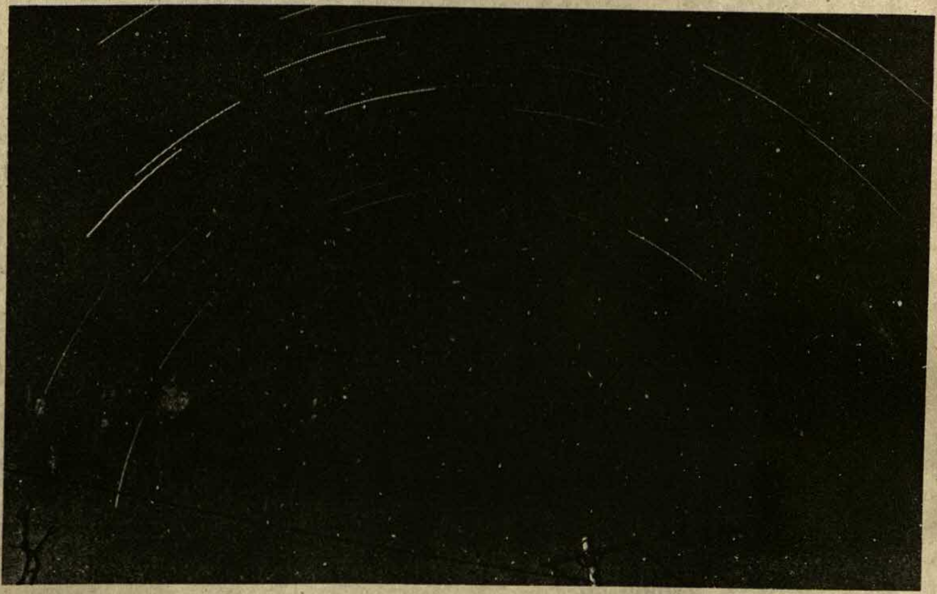


**Figure 1.12:** Time exposure with the camera pointed towards the South Celestial Pole. How long was the lens of the camera open?

# 2

# Earth

The planet Earth is our home in the universe. To the ancient Egyptians and Mesopotamians the earth *was* the universe. They pictured it as a huge platform over which hovered the goddess of the stars. She swallowed the sun each evening and returned it to the sky each morning. Even at the time when Columbus set sail to search for a new route to the East, there were still some people who thought that the earth was flat and that Columbus would surely fall off the edge if he sailed far enough.

## The shape of the earth

The early Greeks were among the first to reject the idea of a flat earth. They reasoned that the earth must be round because of the circular shadow it casts on the moon during an eclipse. They had also noticed the way ships seemed to sink below the horizon as they sailed away over the sea.

Today we have additional evidence of the roundness of the earth in photographs taken from artificial satellites. (See figure 2.1.)

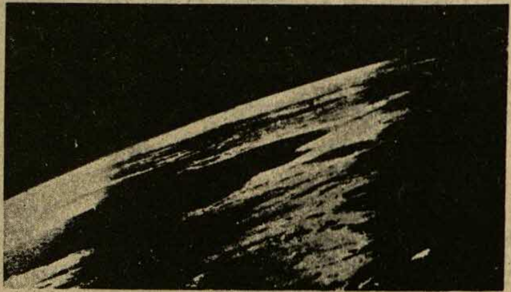


**Figure 2.1:** The roundness of the earth. A photograph taken from a satellite about one hundred kilometres above the earth's surface.

We now know that the earth is not a perfect sphere but is flattened slightly at the poles.

## The rotation of the earth

The fact that the earth is round was more or less accepted by educated people two thousand years ago, but the idea that it rotates was not generally accepted until about two hundred years ago.

The Greek philosophers said that the earth was the largest object in the universe; that it was in fact the centre of the universe and therefore far too heavy to move. This idea, stated by Claudius Ptolemy about A.D. 200, persisted through the Dark Ages for more than a thousand years. It was one of the official beliefs of the times; anyone who questioned these beliefs was in trouble.

One of the first to seriously challenge the idea that the earth was the centre of the universe was the Polish astronomer, Nicolaus Copernicus (1473–1543). Just before he died, he published a book in which he stated that the sun, not the earth, was at the centre of the system. He reasoned that the earth rotated on an axis, giving us night and day, and revolved around the sun, giving us the cycle of the seasons. (See figure 2.2.)

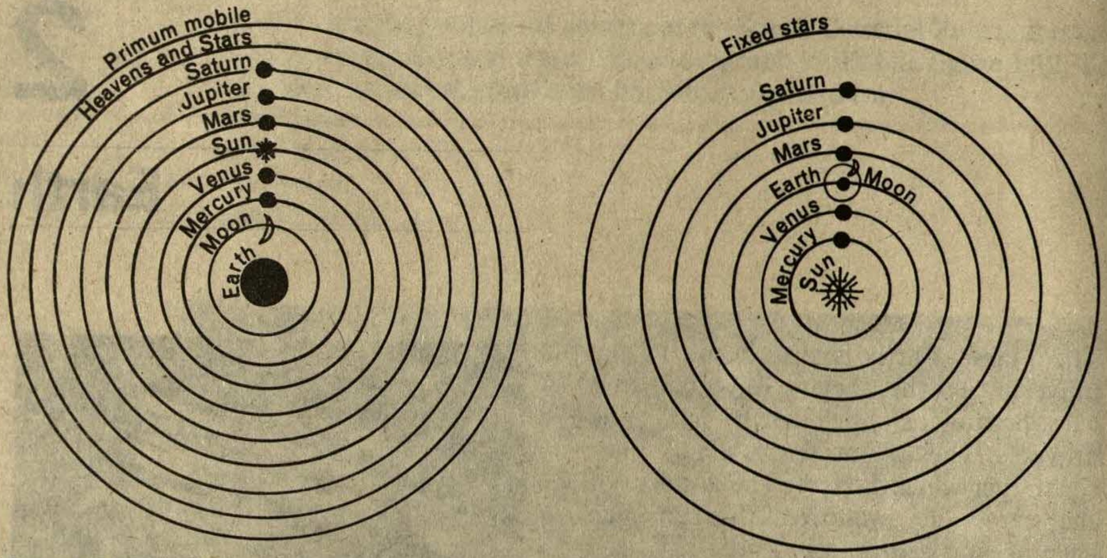


**Figure 2.2:** These diagrams show two theories about the universe. The one on the left shows Ptolemy's theory and the one on the right Copernicus'.

## Proof of rotation

Because we are on the earth it is not easy to obtain evidence to show that, as night turns to day, it is we who are moving and not the sun.

If a pendulum were set swinging freely at the North or South Pole, it would be noticed after about an hour that the direction of its swing was changing. This change is due to the fact that the earth is rotating but the pendulum is not rotating with it. Therefore, the relative positions of the earth and the pendulum's swing (which we call the direction of the swing) change.

Experiment 2.2 is a similar experiment that can be done in a school assembly hall.

## Proof of revolution around the sun

Three observations give proof that the earth revolves around the sun. These are

- the changing brightness of planets
- the changing night sky
- the cycle of the seasons.

***The changing brightness of planets.*** At one particular period Mars appears at its brightest, while about twelve months later it is in a different part of the sky and much fainter. This can be explained by the revolution of the planets around the sun. Mars takes nearly twice as long to circle the sun as the earth does. For this reason, at one time both Mars and the earth will be on the same side of the sun and so fairly close together, thus Mars will look bright. Twelve months later they will be on opposite sides of the sun and so further apart, and Mars will appear fainter.

***The changing night sky.*** The stars seen at night in summer are different from those seen at night in winter. This is explained in figure 2.3 and is further evidence of the earth's revolution around the sun.

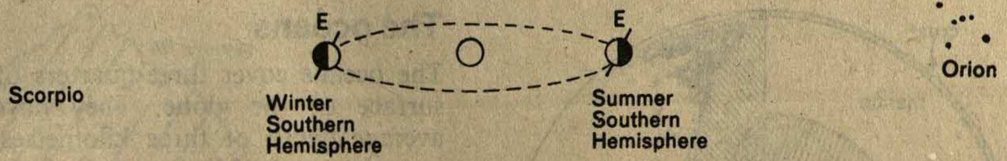


**Figure 2.3:** Different constellations are seen in summer and winter. Observers in the southern hemisphere see Scorpio in winter and Orion in summer. This is evidence of the earth's revolution around the sun.

***The cycle of the seasons.*** The seasons are explained by the following two facts.

- The earth revolves around the sun.
- The axis of spin of the earth is tilted in relation to the axis of revolution around the sun.

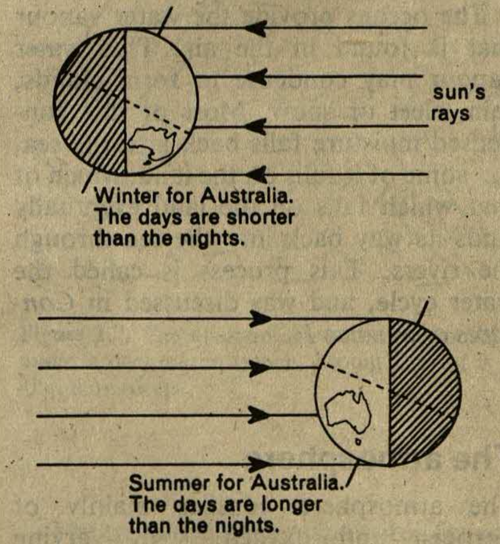


**Figure 2.4:** The seasons are evidence of the earth's revolution around the sun.

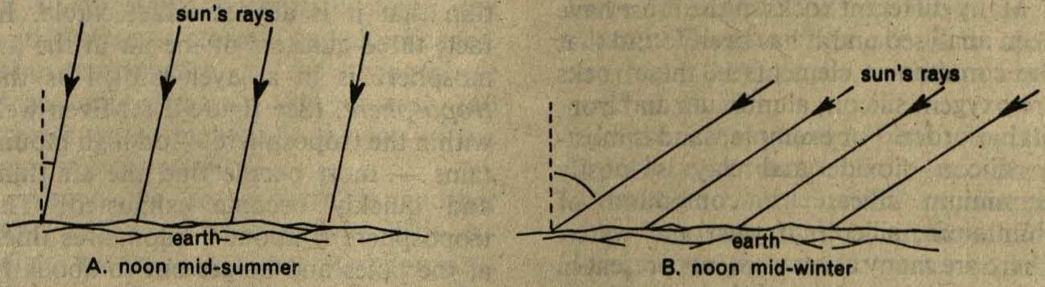
Figure 2.4 shows why the period of darkness for winter days in the southern hemisphere is longer than for summer days. Another reason for the coldness of winter is the larger angle of incidence at which the rays of the sun strike the earth. (See figure 2.5.)

## The composition of the earth

Study of earthquake waves has led scientists to believe that the part of the earth we are living on is a thin *crust*, eight to forty kilometres thick. No one has yet pierced this crust. It is thinnest under the oceans and thickest under the continents.

Beneath the crust are first the *mantle*, to a depth of 2900 kilometres, and then the *core*, extending to the centre of the earth. (See figure 2.6.)

The weight of the whole earth has been calculated. It is approximately 6 000 000 000 000 000 000 000 tonnes. (This can also be written as $6 \times 10^{21}$ tonnes.)



A. noon mid-summer

B. noon mid-winter

**Figure 2.5:** One reason for the heat of summer is the small angle of incidence at which the sun's rays strike the earth. These diagrams are drawn for New South Wales.

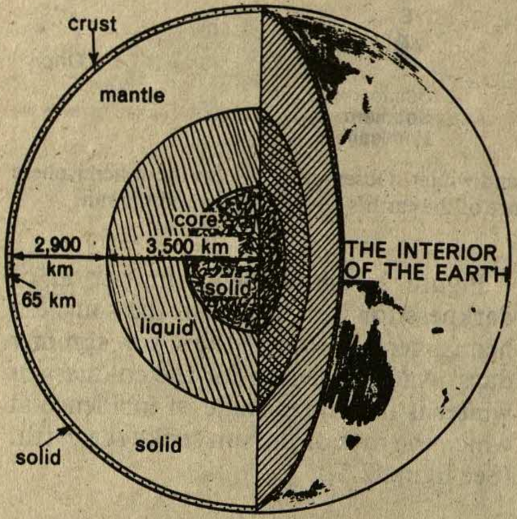


**Figure 2.6:** The interior of the earth as scientists at present believe it to be. The mantle is thought to be solid, the outer core liquid and the inner core solid, even though its temperature is estimated to be 4000°C.

For the earth to have this weight, the material of which it is made must be about 5½ times as heavy as water. The rocks in the crust, however, are only about 2½ times as heavy as water. Therefore, the core must be very much denser than the crust. (Density is explained in chapter 14.) This and other facts have led scientists to believe that the core is composed of iron and possibly nickel.

Many different rocks in the crust have been analysed and it has been found that the commonest elements in these rocks are oxygen, silicon, aluminium and iron, in that order. For example, sand is mostly silicon dioxide and clay is mostly aluminium silicate, a compound of aluminium, silicon, oxygen and water. There are many other elements present in the crust, but these are only in small proportions.

## The oceans

The oceans cover three-quarters of the surface of the globe. They have an average depth of three kilometres, increasing to ten kilometres in the great ocean trenches that lie along some of the edges of continents. The pressure at the bottom of these trenches is enormous, as much as 900 kilograms per square centimetre. Water, as we have already discovered, is practically incompressible; for this reason, at these great depths water is very little heavier than at the surface.

The oceans provide the water vapour that is found in the air. This water vapour may condense to form clouds, rain, sleet or snow. Most of this condensed moisture falls back into the sea, but some of it falls on the land. Much of that which falls on the land eventually finds its way back into the sea through the rivers. This process is called the water cycle, and was discussed in *Concepts of Science 1*.

## The atmosphere

The atmosphere consists mainly of nitrogen and oxygen, with varying amounts of water vapour. It extends upwards for about 800 kilometres, although at its greatest altitude it is so thin that it is almost undetectable. In fact, three-quarters of the air in the atmosphere is in a layer known as the *troposphere*. (See figure 2.8.) Even well within the troposphere — on high mountains — most people find the air thin, and quickly become exhausted. The troposphere is about 9 kilometres thick at the poles and bulges out to about 18 kilometres at the equator. The thickness above Australia is about 11 kilometres.

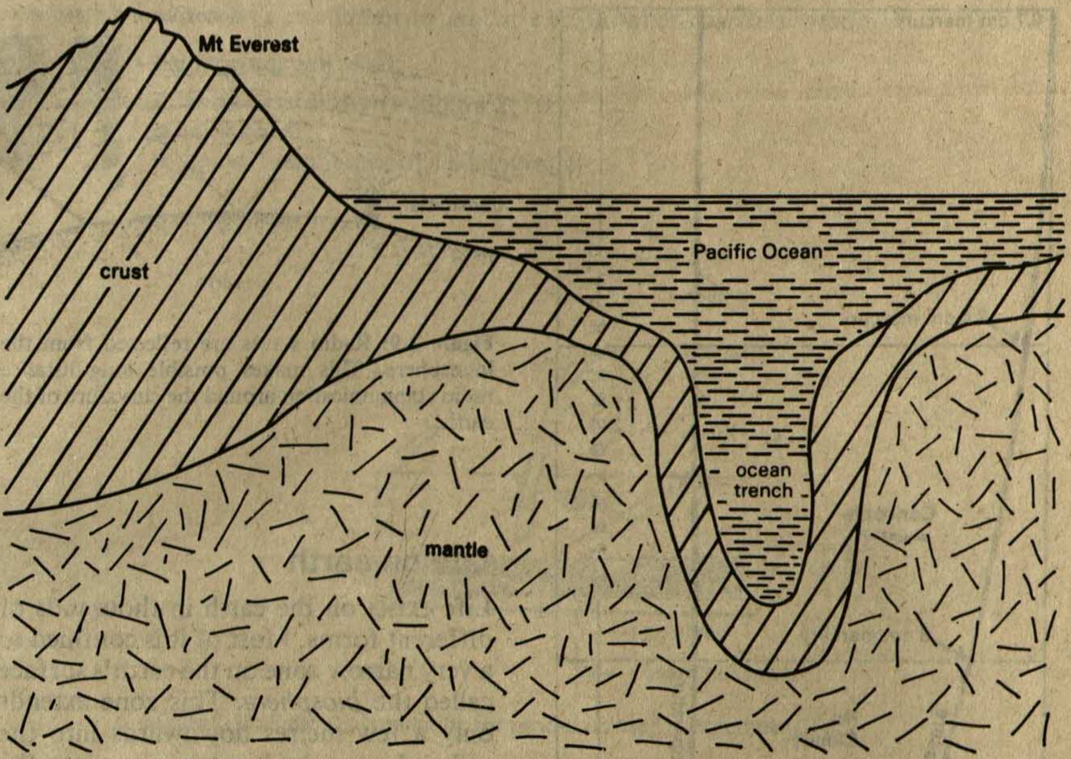


**Figure 2.7:** The diagram shows the relationship between crust and mantle under a mountain range and under a deep ocean trench. Mount Everest is eight kilometres high and the Marianas Trench is eleven kilometres deep.

The troposphere is responsible for our weather. It contains most of the water vapour in the atmosphere and is a zone of turbulence. The air eddies and surges in all directions, forming cyclones and anti-cyclones, storms and hurricanes. The temperature in the troposphere drops approximately 1°C for each 160 metres we go higher. At the top of the layer it is about -50°C.

Above the troposphere is another layer called the *stratosphere*. This extends upwards to about 30 kilometres above the earth's surface. The stratosphere is quite different from the troposphere. It has a uniform temperature of about -55°C and, within it, the winds blow horizontally: at some levels, east, and at other levels, west. These horizontal winds are known as jet streams. Because their speed is often very high, they can be an aid to high-speed air travel.

Above the stratosphere is the *ionosphere*. A feature of the ionosphere is that the air particles in it are charged with electricity, that is, ionized. The ionosphere reflects radio waves back to the earth, making long-distance radio communication possible. See figure 2.9.

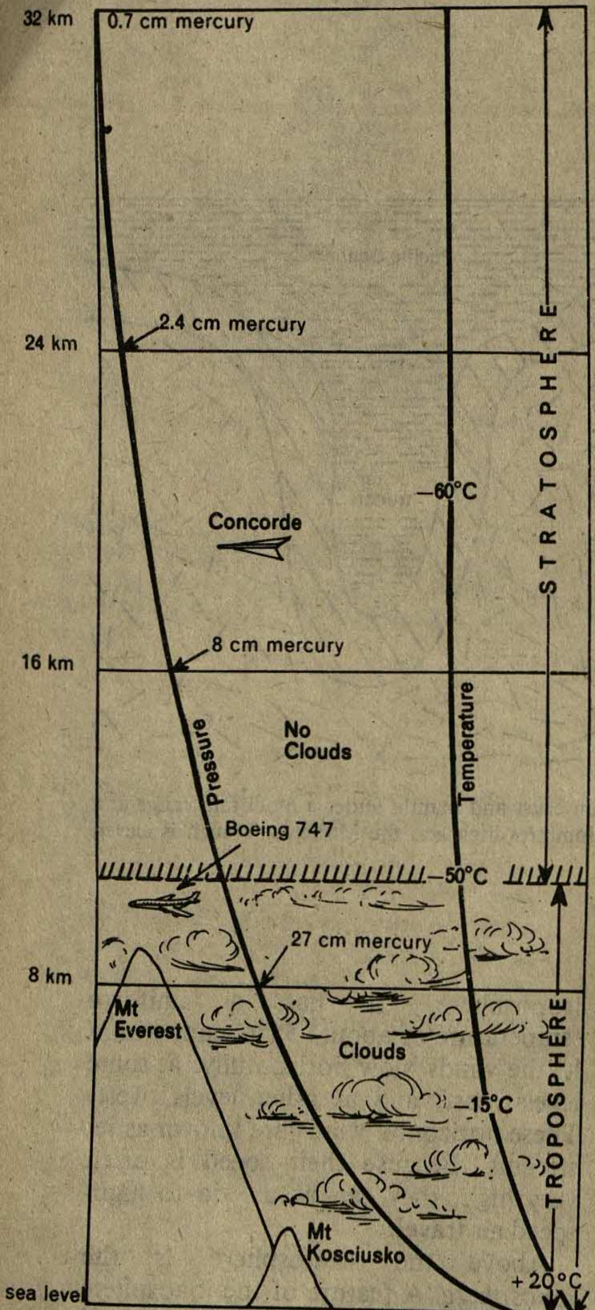


**Figure 2.8:** The atmosphere. Half of it is compressed into the first 5.5 kilometres above the earth's surface.

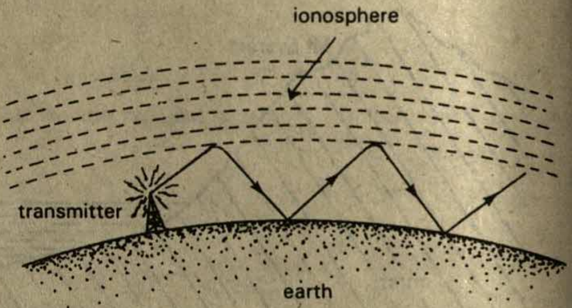


**Figure 2.9:** Radio waves are reflected from the ionosphere. This makes possible long-distance radio communication around the curvature of the earth.

## Life on earth

Life exists on the earth in thousands of different forms. Most of it is confined to a very narrow zone on the earth's surface called the *biosphere*. This zone extends only a few metres downwards into the soil and a hundred metres or so into the air. In fact the tallest trees determine the limits of the biosphere; it extends from their deepest roots to the tops of their highest branches. Birds and insects, of course, fly above the trees but they do not live permanently above the branches.

Life extends much deeper into the oceans: as far down as two hundred metres for most forms of marine life. There are, however, some forms of life in the deepest ocean trenches, ten kilometres below the surface.

**EXPERIMENT**

**2.1**

## *How can a pendulum be used to show that the earth is rotating?*

**Each group will need:**

- apparatus shown in figure 2.10
- long cord
- heavy weight, about 15 kilograms

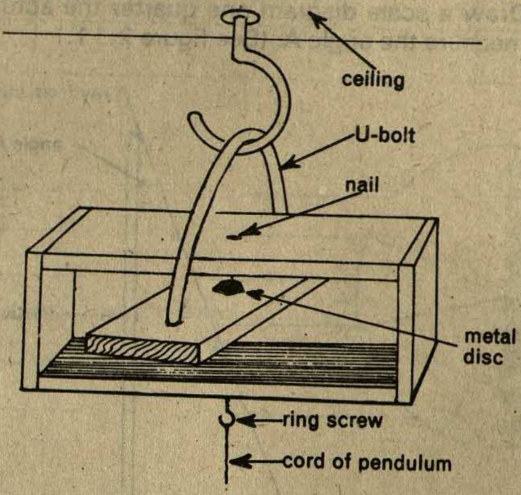


**Figure 2.10:** Suggested mounting for pendulum used in experiment 2.1.

### What to do

- Hang the 15 kilogram weight by a long cord from the ceiling of an assembly hall or gymnasium. One method of hanging the weight, or pendulum, is shown in figure 2.10. This allows the pendulum to turn as it swings.
- Chalk a north–south line on the floor directly beneath the pendulum, pull the pendulum about 2 metres out along this line and release it.
- Note the direction of swing after half an hour and again after one hour.
- Repeat this a number of times.

### Questions

2.1 In which direction did the swinging pendulum appear to turn, clockwise or anticlockwise?
2.2 What is your explanation for the turning of the pendulum?
2.3 Why use a heavy weight and a long cord?

**EXPERIMENT**

**2.2**

## *Measuring the angle at which the sun's rays strike the earth at noon on a particular day*

**Each group will need:**

- retort stand
- spirit level with bubble for the vertical

**What to do**

- Place the retort stand on a flat area in sunlight at noon. (*Note:* **During the period of Eastern Summer Time in southern states, make the measurement at 1 p.m. by the clock.**) Use the spirit level to check that the stand is vertical.
- Measure the length of the shadow cast by the sun and also the height of the stand.
- Draw a scale diagram one quarter the actual size in your workbook and measure the angle A. (See figure 2.11.)

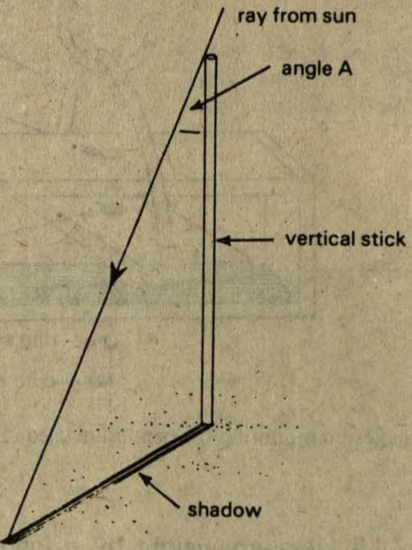


**Figure 2.11:** Using a shadow stick to measure the angle at which the sun's rays strike the earth's surface at noon.

### EXPERIMENT 2.3

*Using figure 2.12 to measure the angle of incidence of the sun's rays during summer and winter*

**What to do**

- Figure 2.12 is drawn for Sydney, which has a latitude of 34° south. You will need to redraw the figure if you live at a different latitude. The latitudes of other eastern capitals are: Brisbane 28° S, Melbourne 38° S, Hobart 45° S.
- The line BC represents the shadow stick standing vertically on the earth's surface. Measure the angle A, which is the angle the sun's rays make with the shadow stick.

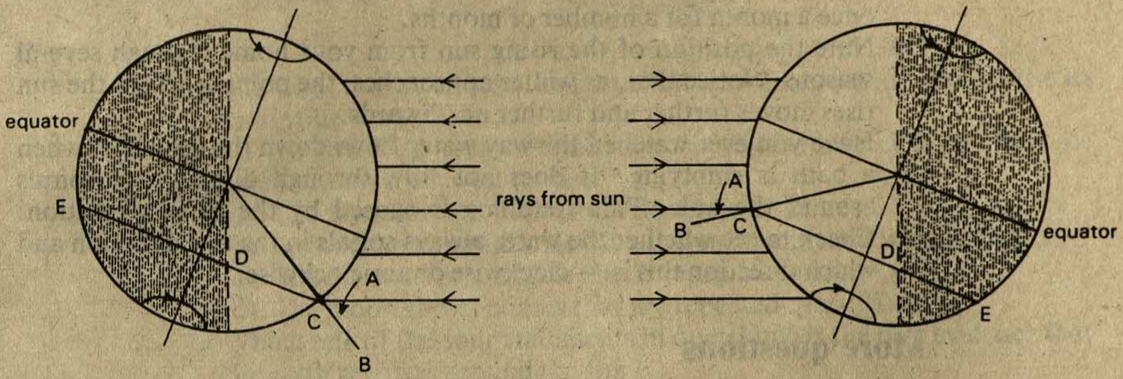
**Question**

**2.4** What angle do the sun's rays make with the vertical on (a) 22 June, (b) 22 December?

- CD represents the hours of daylight and DE represents the hours of darkness. Measure and record these lengths for 22 June and 22 December.

- Draw and complete the following table.

| Date | Angle of sun's rays (A) | Length of day (CD) | Length of night (DE) |
|---|---|---|---|
| 22 June | | | |
| 22 December | | | |



Sydney winter
22 June

Sydney summer
22 December

**Figure 2.12:** The earth spins about an axis inclined at 22° to the perpendicular to the rays coming from the sun. This spinning gives us day and night. The earth also travels around the sun once in a year. This revolution and the tilt of the earth's axis of spin give us the seasons. In this diagram the earth has been sketched as it would appear on opposite sides of the sun.

## Earth

1. The earth rotates on an axis and revolves around the sun.
2. A swinging pendulum supplies evidence for the rotation of the earth.
3. The changing night sky, changes in the brightness of some of the planets, and the cycle of the seasons supply evidence of the revolution of the earth.
4. The earth probably has a crust, mantle and core.
5. The most common elements in the earth's crust are oxygen, silicon and aluminium.
6. Most of the earth's atmosphere is compressed into the troposphere, the lowest layer of the atmosphere.

## Spelling list

altitude
axis
biosphere
compressible
hemisphere
ionized
ionosphere
mantle
pendulum
revolve
rotate
satellite
stratosphere
troposphere
turbulence

## Things to do

**2.5** Measure the angle between the sun's rays and the vertical at noon once a month for a number of months.

**2.6** Note the position of the rising sun from your home through several seasons. Notice that, as winter approaches, the point at which the sun rises moves further and further northwards.

**2.7** Have you ever watched the way water flows down the plug hole when a bath is emptying? It does not flow through directly but spirals around the hole. This spiralling is caused by the earth's rotation. Check to see whether the water always spirals in the one direction and which direction this is — clockwise or anticlockwise.

## More questions

**2.8** List as many observations as you can that show that the earth is round.

**2.9** Draw a cross-sectional diagram to show the latest ideas about the structure of the earth.

**2.10** Why do climbers of very high mountains need to carry oxygen?

**2.11** The Concorde flies in the stratosphere. Why would engineers design an aircraft to fly where the air is so thin?

**2.12** The longest day of the year is 22 December, whereas January is usually the hottest month. Why?

**2.13** Find out something about the animals that live at great depths in the ocean. (R)

**2.14** Why do people holidaying in the snow at great altitudes become sunburnt during fine weather?

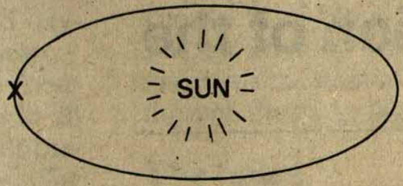
**2.15** A litre of air in the stratosphere weighs much less than a litre at sea level. Yet a litre of water at a great depth in the ocean weighs about the same as a litre of water at sea level. Why?

## Test yourself (chapter 2)

Write the answers to questions 1 to 5 in your workbook.

1. Name the three commonest elements in the rocks of the earth's crust.
2. State one fact that shows that the earth rotates.
3. State one fact that shows that the earth revolves around the sun.

4. State two reasons for winter being colder than summer.
5. The diagram below represents the earth moving around the sun. How long will it take the earth to return to position X?



In questions 6 to 9, choose the best answer to each question and write its letter in your workbook.

6. Of the following true statements, which is the best evidence that the earth rotates from west to east?
   - (a) The sun rises in the east and sets towards the west.
   - (b) A swinging pendulum slowly turns in an anticlockwise direction.
   - (c) The seasons form a cycle that is repeated yearly.
   - (d) The moon shows phases that are repeated every 28 days.
7. Which one of the four statements in question 6 is the best evidence that the earth revolves around the sun?
8. Of the following true statements, three can be directly observed by a student but one must be accepted on other people's evidence. The one based on other evidence is:
   - (a) The sun radiates heat and light.
   - (b) The sun is 93 million miles from the earth.
   - (c) The sun rises approximately in the east and sets approximately in the west.
   - (d) The shadow cast by the sun is shortest at noon.
9. Of the following pieces of information, which one would be of least value to a space scientist planning a trip to the moon?
   - (a) The moon orbits around the earth.
   - (b) The earth is spinning.
   - (c) The earth is the third planet out from the sun in the solar system.
   - (d) The moon has its own gravity.

# 3

# Circulation of the blood

Until about three hundred years ago it was thought that the blood in our bodies flowed to and from the heart like a tide. William Harvey, an Englishman, disproved this theory by dissecting corpses and carrying out many experiments on living humans. He found that the blood circulates continuously through the body. In this chapter we shall study this circulation.

## The circulatory system

This system does the following things:

- It carries food to all cells of the body.
- It carries oxygen to all cells of the body.
- It carries wastes away from the cells of the body.

This carrying or transport is done by the blood; it circulates through a closed system of vessels diagrammatically shown in figure 3.1.

Let us start at the beginning of the voyage food takes to the cells. Our food must be changed by the digestive system into a soluble form so that it can be absorbed by the blood.

Digestion begins in the mouth, where the food is mixed with saliva from the salivary glands. Saliva contains a special substance, called an enzyme, that helps to break starch down into sugar. Swallowing forces food from the mouth to the stomach. The stomach produces digestive juices that contain mainly hydrochloric acid and enzymes. These juices start breaking down proteins and fats into smaller particles. From the stomach, the food is pushed through the duodenum into the small intestine. Again, it is a type of muscular action that urges the food forward. Two narrow tubes lead into the duodenum. One of these brings bile from the liver to emulsify fats and the other brings pancreatic juice from the pancreas. This juice, together with more enzymes made by the walls of the intestine, completes the digestion.

At this stage:

- The carbohydrates have been converted to glucose.
- The proteins have been converted to amino acids.
- The fats have been converted to fatty acids.

The particles of these end-products of digestion are now small enough to pass through the walls of the small intestine into very fine blood vessels called capillaries. These capillaries join together to form the great portal vein, which leads to the liver. The liver is a large food storage organ. It supplies nourishment when there is little food in the intestine and during sustained physical activity such as long-distance running. From the liver the blood passes into the right side of the heart. (See figure 3.1.)

The heart pumps this blood through the lungs, where it receives oxygen. The blood, now rich in both food and oxygen, returns to the left side of the heart.

From here the heart pumps the food- and oxygen-rich blood out to cells in all parts of the body. The blood vessels carrying this blood are called arteries. The food and oxygen reaches the cells by passing through the walls of capillaries. Waste products from the cells are at the same time absorbed into the bloodstream. The circulation is completed by blood returning through veins to the right side of the heart.

Each person has about 100 000 kilometres of blood vessels in his body. The six litres of blood in the transport system of the human male are circulated through the body about 1000 times daily.

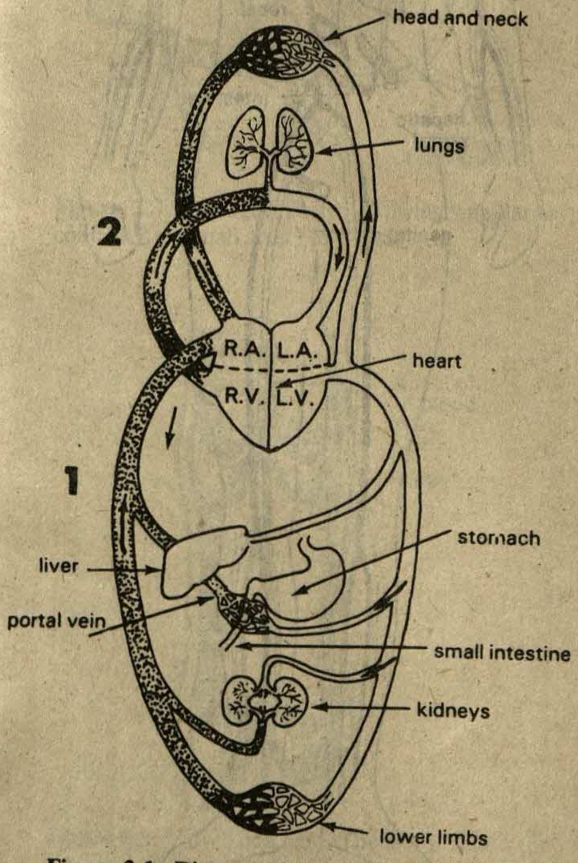


**Figure 3.1:** Diagram showing the circulation of the blood. 1 — systemic circulation; 2 — pulmonary circulation; R.A. — right atrium; R.V. — right ventricle; L.A. — left atrium; L.V. — left ventricle.

## The heart

The heart is a muscular pump that drives blood through the blood vessels of the body. It does this by contracting at regular intervals, thus squeezing the blood out under pressure. These pulses of pressure may be felt with the fingers in those blood vessels near the surface of the body. The pulse is usually tested at a patient's wrist.

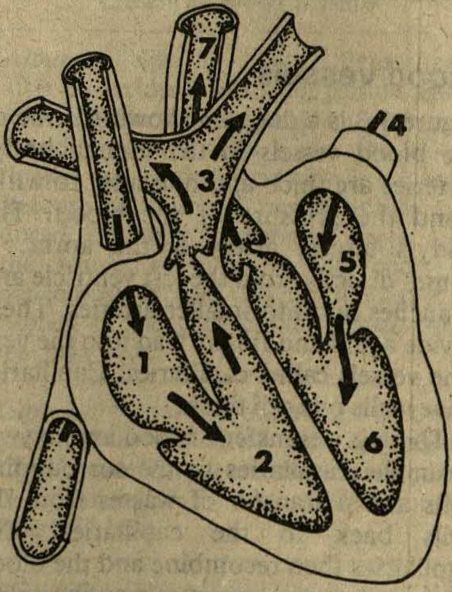


**Figure 3.2:** Diagram of human heart. 1 — right atrium; 2 — right ventricle; 3 — pulmonary arteries; 4 — pulmonary veins; 5 — left atrium; 6 — left ventricle; 7 — aorta. These parts may be identified by dissecting a sheep's heart. It is preferable to obtain a heart with the vessels attached.

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Figure 3.2 is a diagram of a human heart. As in all mammals, the heart is divided into two halves. It is therefore a double pump. The right side pumps blood to the lungs; the left side pumps the blood received back from the lungs to the rest of the body. The circulation of blood through the lungs is called the pulmonary circulation. The circulation through the rest of the body is called the systemic circulation. Figure 3.1 shows these two circulations.

Each side of the heart has two chambers. The top chamber on each side is an inflow chamber and is called the atrium or auricle. The bottom chamber on each side is an outflow chamber and is called the ventricle. The atria contract together, squeezing blood through valves into the ventricles. Almost immediately afterwards, the ventricles contract, squeezing blood out through the arteries.

## Blood vessels

Figure 3.3 is a diagram showing some of the blood vessels in the human body. Arteries are thick and muscular to withstand the pressure of the blood. The body's largest artery is the aorta. It comes directly from the left ventricle and branches out into smaller arteries. These divide again and finally lead into the very fine vessels called capillaries. Capillaries have walls one cell thick.

There is a transfer of food and oxygen from the capillaries to the surrounding cells and a transfer of wastes from the cells back to the capillaries. The capillaries then recombine and the blood returns to the heart through veins. Figure 3.4 is a diagram showing capillaries from a small artery recombining to form a small vein.

Veins are thin-walled vessels with interior valves that stop the blood from

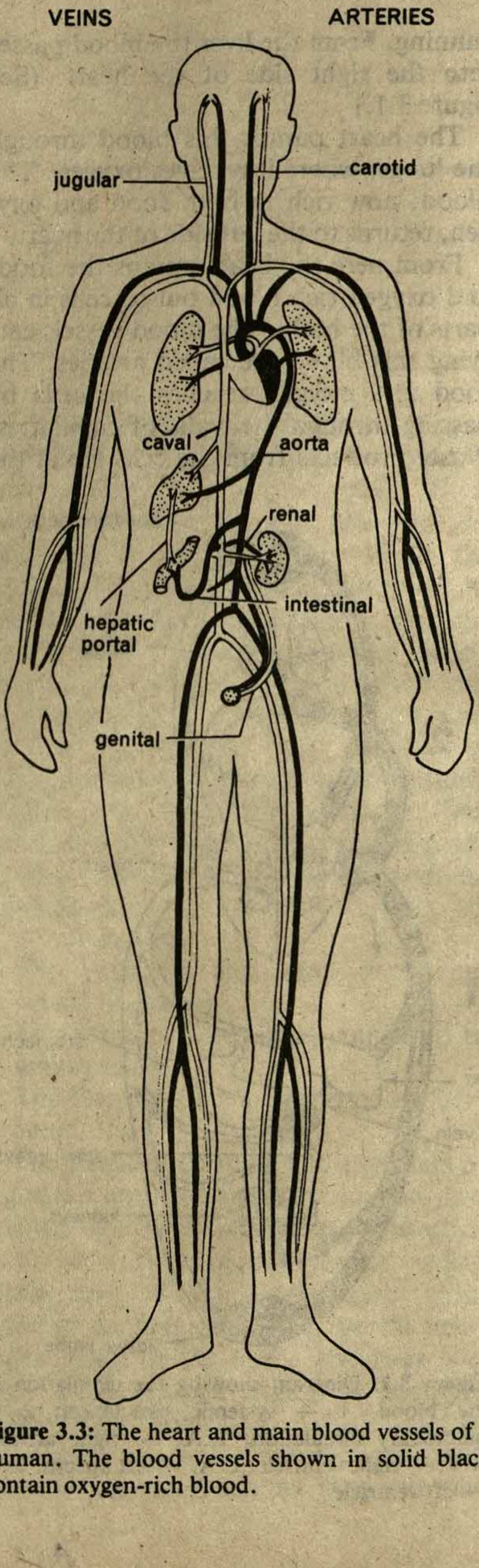


**Figure 3.3:** The heart and main blood vessels of a human. The blood vessels shown in solid black contain oxygen-rich blood.

slipping backwards. Figure 3.5 shows some of these valves. They allow a flow of blood in one direction only — towards the heart.

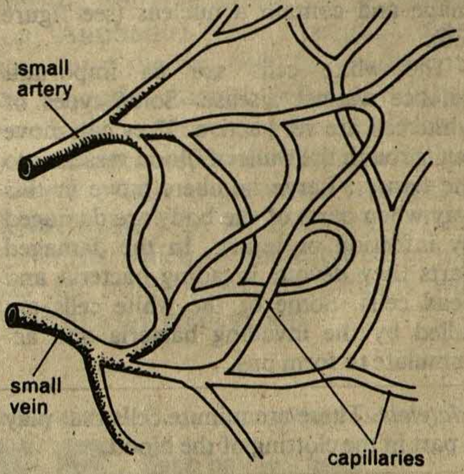


**Figure 3.4:** Enlarged sketch showing capillaries connecting a small artery to a small vein.

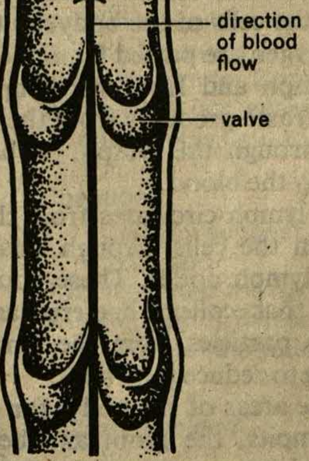


**Figure 3.5:** Valves in a vein. The arrow shows the direction of blood flow. If there were no valves in the veins, blood would run into people's feet every time they stood up. Valves in the veins fill up and stop this back flow. Faulty valves are the cause of varicose veins.

## Blood

Blood is a suspension of cells in a liquid called plasma. The plasma consists of water containing particles in solution. Some of these particles are

- food particles from the digestive system
- waste particles from the cells
- particles necessary for such functions as clotting and reducing shock (see table 3.1)
- mineral salts.

The plasma makes up a little more than half the volume of the blood. In an average adult male with 6 L of blood, 3.25 L are plasma and the rest is blood cells. Some of the important substances dissolved in the plasma are listed in table 3.1.

**Table 3.1:** The functions of some substances present in blood plasma

| |
|---|
| *Albumin* helps the body to fight shock after an accident. In shock, plasma tends to leak from the capillaries into the surrounding tissues. This makes the blood thicker and so the circulation is choked. Because of this, cell respiration is reduced, the body temperature drops and the whole working of the body is dangerously slowed down. Albumin is a protein in the plasma that reduces this leaking effect. |
| *Globulin* carries the antibodies that are produced in the blood after infection. These antibodies prevent further infection by destroying the disease organism if it reenters the body. |
| *Fibrinogen* causes blood to clot when it is exposed to the air. When blood flows from a wound the fibrinogen forms a network of fibres. These trap the blood cells and thus form a clot that prevents further bleeding. |

Table 3.2 describes the different kinds of cells in blood.

**Table 3.2:** Blood cells

*Red cells.* In an average man there are about 25 million million red cells in the blood. These cells are small round discs that are thicker at the edges, as shown in figure 3.6.

The red cells are made in the marrow of certain bones. Unlike other cells, they contain no nucleus but are packed with an iron compound called haemoglobin. Haemoglobin combines readily with oxygen. This enables the blood to carry much more oxygen than would dissolve in the plasma alone. When combined with oxygen the haemoglobin in the red cells gives a vivid red colour to the blood. After this oxygen has been removed the blood is a bluish-red colour.

*White cells.* The white cells are outnumbered 500 to 1 by the red cells. Unlike the red cells they are roughly spherical in shape and contain a nucleus (see figure 3.6).

The white cells are an important defence against disease. Some types of white cell are very active. They can move out through the walls of blood vessels into the tissues. Large numbers move in this way when parts of the body are damaged by infection or injury. In the damaged parts they devour invading bacteria and dead cells. Some of the white cells are killed by the invading bacteria and accumulate to form pus.

*Platelets.* These are minute cells that play a part in the clotting of the blood.

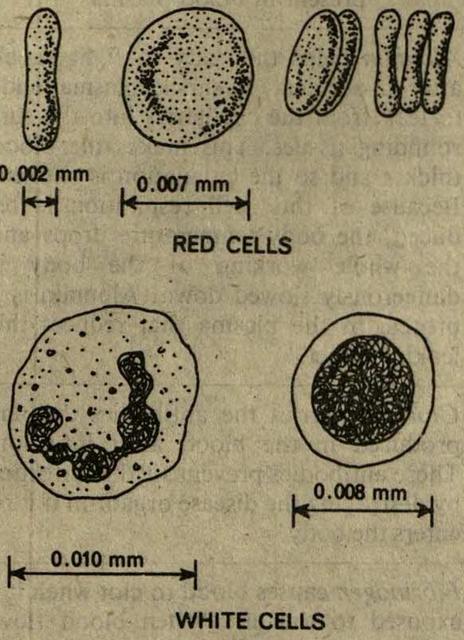


**Figure 3.6:** Cells from human blood. An edge view and a face view of the red cells are shown. Two nuclei of different shape are shown in the white cells.

## The lymph system

Lymph is a colourless fluid similar to plasma. It fills all the minute spaces between the cells of the body, so that food and oxygen are passed from the blood to the lymph and from the lymph to the cells. Waste products from the cells also pass through the lymph, to be carried away by the blood.

The lymph circulates from the spaces between the cells through small bodies called lymph nodes. These nodes act as filters that collect bacteria and other foreign particles from the lymph, thus helping to reduce infection.

Some areas of the body, for example, the armpits, the groin and behind the ears and knees, contain a concentration of lymph nodes. This is why an infection in the foot can cause swelling and inflammation behind the knee or in the groin.

## Transfusions

Patients suffering from certain illnesses, and accident victims who have lost a great deal of blood, often require transfusions. Care must be taken in selecting suitable blood for a transfusion. Antibodies in one person's blood may cause the red cells of another person's blood to stick together. If this happened, the result could be the death of the patient receiving the transfusion. There are four main kinds (groups) of blood, namely O, A, B and AB. Table 3.3 shows which of these blood groups may be safely given to patients with blood of a different group.

**Table 3.3:** Mixing blood groups

**Recipient's group**

| **Donor's group** | A | B | AB | O |
|---|---|---|---|---|
| A | ✓ | | ✓ | |
| B | | ✓ | ✓ | |
| AB | | | ✓ | |
| O | ✓ | ✓ | ✓ | ✓ |

✓ indicates that a transfusion may be safely given.

EXPERIMENT 3.1 *Does your pulse rate vary?*

**Each pair will need:**

- watch with sweep second hand

**What to do**

- Place the tips of your fingers on the inside of your wrist, on the thumb side, about 5 cm back from the base of your thumb.
- Count the number of pulses you can feel per minute. This is the pulse rate.
- Take the pulse rate in the following positions: lying, sitting and standing.
- Take the pulse rate after walking briskly for 2 min and then after running on the spot for 2 min.
- After the last exercise, take the pulse rate every 3 min to find out how long it takes for it to return to normal.

**Questions**

3.1 Can you suggest a reason for the fact that pulse rates vary from person to person?
3.2 Why does the pulse rate increase after exercise?
3.3 Suggest a reason for the variation from person to person in the time taken for the pulse rate to return to normal.

EXPERIMENT 3.2 *Examining blood*

**Each group will need:**

- clean needle
- methylated spirits
- two clean microscope slides
- microscope

**What to do**

- Wash your hands thoroughly.
- Dip the tip of a clean needle in methylated spirits for a few minutes.
- Whirl your arm in a circle about your shoulder ten or twelve times.
- Clean the skin of one finger with methylated spirits.
- Squeeze this finger and prick it just behind the nail.
- Put the drop of blood that appears on a clean glass slide.
- Using the edge of another clean slide, spread the blood out to form a thin smear.
- Examine the smear under low, medium and high power lenses of a microscope.
- Compare what you see under the high power with figure 3.7.

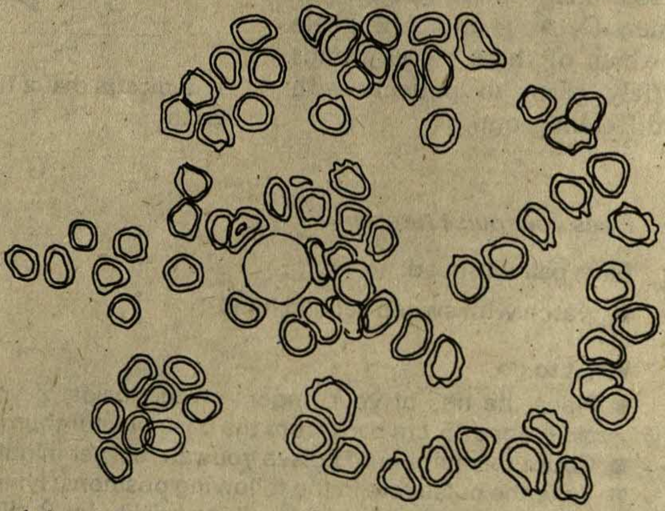


**Figure 3.7:** Blood viewed through a high-powered microscope.

**Questions**

3.4 Draw a diagram of some of the cells that you see.
3.5 Red cells outnumber white cells by about 500 to 1. Have you been lucky enough to see a white cell?
3.6 What are the functions of red cells and white cells?

**EXPERIMENT**

**3.3**

### *Examining a sheep's heart*

**Each group will need:**

- sheep's heart with blood vessels attached (This may be obtained from a butcher by special order.)
- pieces of glass tubing to fit blood vessels
- filter funnel
- rubber tubing
- probe
- scalpel
- scissors

**What to do**

- Examine the heart and try to identify the four main blood vessels shown in figure 3.8. If the blood vessels have been removed, test the openings where they were by trying to pour water into them through a glass tube. The water will flow into the veins but not into the arteries, because of the action of the valves in the heart.

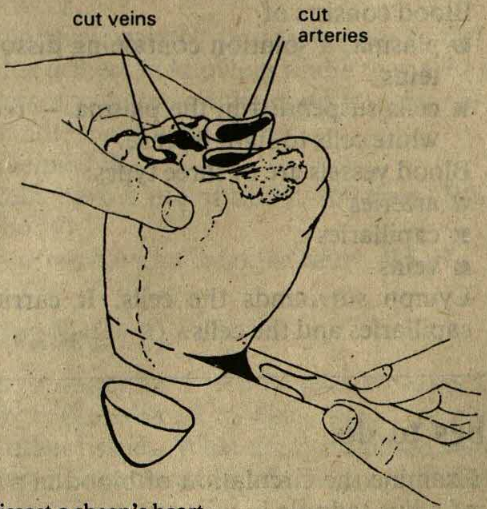


**Figure 3.8:** How to dissect a sheep's heart.

- Carefully cut discs from the heart, starting from the bottom (the side opposite the blood vessels). The discs should be about 1 cm thick, as shown in figure 3.8. Stop cutting about 1 cm from an atrium.
- Lay the discs in order on a sheet of paper.
- Look at the muscular walls of the ventricles.
- Look for white flaps with small white threads joined to them. These are valves.
- Cut open the two arteries where they joined the heart and again look for valves. The sound of the heartbeat is the noise made when the valves snap shut during pumping.

## Spelling list

albumin
antibodies
aorta
arteries
atrium
capillary
circulation
coagulate
diagrammatic
enzyme
fibrinogen
globulin
haemoglobin
inflammation
lymph
pulmonary
systemic
ventricle

## Circulation of the blood

1. The circulatory system consists of
   - blood, the transport material
   - blood vessels to conduct the blood
   - a heart to keep the blood moving.
2. Blood consists of
   - plasma, a solution containing dissolved food, wastes and proteins
   - cells suspended in the plasma — red cells to carry oxygen and white cells to fight disease.
3. Blood vessels are of three types:
   - arteries
   - capillaries
   - veins.
4. Lymph surrounds the cells. It carries substances between the capillaries and the cells.

## Things to do

**3.7** Examine the circulation of blood in a tadpole's tail. Wrap the body of a live tadpole in wet cottonwool and examine the tail through the low power lens of a microscope.

**3.8** Obtain some cow's blood that has been treated with anti-coagulant. Bubble first oxygen and then carbon dioxide through the blood and note any changes in colour.

**3.9** Read about William Harvey and how he discovered the way the blood circulates through the body.

**3.10** Very few species of animals have a four-chambered heart like the mammals. Read about other kinds of hearts. How many chambers are there in the heart of a frog? How is blood circulated through the body of a worm?

## More questions

**3.11** Suppose you have eaten a meat sandwich for lunch. Work out the path by which the main food substances in the sandwich pass from your mouth to the cells of your body.

**3.12** What features of the small intestine make it especially adapted for absorbing food? (R)

**3.13** What is the function of the large intestine in the body of a mammal? (R)

**3.14** Proteins are partly digested by enzymes in the stomach. Why, then, does the stomach not digest itself, since its walls are mainly made up of protein? (R)

**3.15** Explain how red cells differ from white cells. How is pus formed?

**3.16** A person is involved in a road accident in which his liver is badly damaged. What adverse effects could this have on the whole body? Will the liver grow again if the person survives? (R)

**3.17** People suffering from anaemia have a shortage of red cells in their blood. What symptoms would you expect such people to show? Explain your answer.

**3.18** What are "pressure points" on the human body? Where are they, and what value is there in knowing where they are? (R)

**3.19** Suppose a person is bitten on the hand by a funnel-web spider. How would you handle the situation? (R)

**3.20** What is leukaemia? (R)

**3.21** Red blood cells have a life of about 100 days. Where are new ones made in the body?

**3.22** Athletes very often have an enlarged heart. Why?

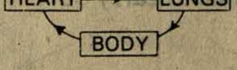
## Test yourself (chapter 3)

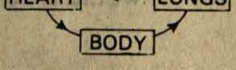
Write the answers to questions 1 to 5 in your workbook.

1. While it is in certain blood vessels, blood receives and gives up substances to other tissues. What are these blood vessels called?
2. Name an organ in mammals in which gas is absorbed from the atmosphere.
3. Which type of blood vessels have valves?
4. What kind of blood cell helps to protect the body from infection?
5. Name the substance in blood that carries oxygen to the cells of the body.

In questions 6 to 10, choose the best answer and write its letter in your workbook.

6. In the heart of a mammal, the pump for the systemic or body circulation is the
   (a) right ventricle
   (b) left ventricle
   (c) right atrium
   (d) left atrium.
7. To answer this question, refer to the four diagrams below.

P


Q


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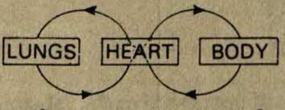
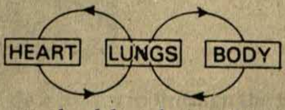


S


The diagram that most accurately represents the blood circulation in a mammal is

(a) P (b) Q (c) R (d) S.

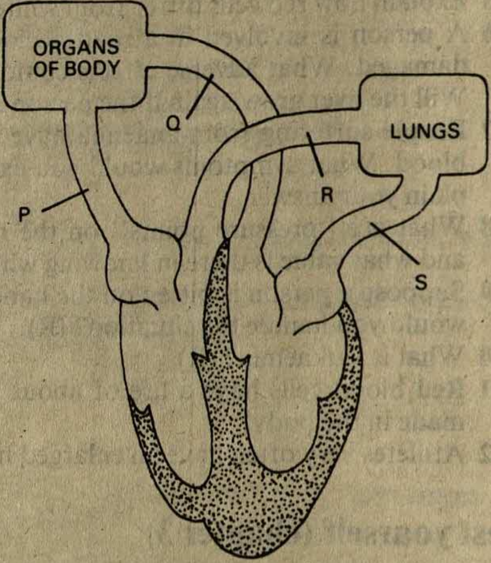


**Figure 3.9**

8. Figure 3.9 shows diagrammatically the pathway taken by circulating blood through the heart. The concentration of oxygen would be greater in
   (a) P than Q
   (b) S than R
   (c) R than Q
   (d) P than S.
9. An accident victim has a deep cut in the leg from which bright red blood is coming out in spurts. To give first aid to this person you should
   (a) try to stop blood flowing in the arteries supplying the leg
   (b) try to stop blood flowing in the veins draining the leg
   (c) wait for the blood to clot and so seal the wound naturally
   (d) raise the person's chest to give more resistance to the flow of blood.
10. In the situation described in question 9, which of the four suggestions would it be least advisable to carry out?

# 4

# Excretion

The body of a living thing is like a chemical factory. Raw materials are brought into the factory, new products manufactured and, as part of the process, there are wastes to be got rid of. In a living thing, all the chemical reactions that take place are together called the *metabolism* of the organism. In these chemical reactions waste products are formed, which must be removed. The removal of the waste products is called excretion.

This chapter deals with the formation of waste products in the human body and the ways they are excreted.

## Waste products

***Carbon dioxide.*** During respiration, food and oxygen are converted into energy. The waste products of this process are carbon dioxide and water. The fact that carbon dioxide is excreted may be demonstrated using the apparatus shown in figure 4.1.

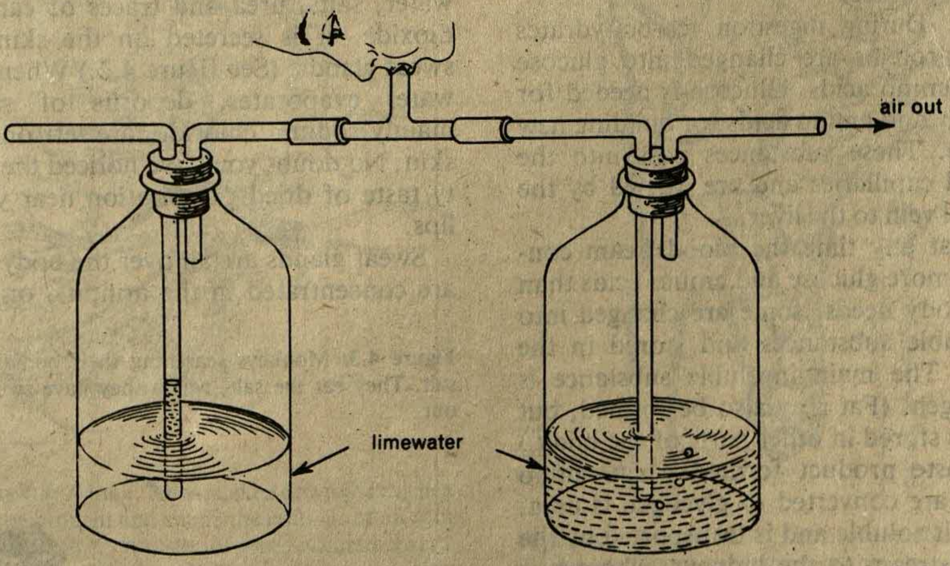


**Figure 4.1:** Excretion of carbon dioxide. When the person breathes in, air is drawn in through the left-hand bottle. When the person breathes out, air is forced out through the right-hand bottle as shown A white precipitate forms in the right-hand bottle, showing that carbon dioxide is excreted.

Exhaled air clearly contains more carbon dioxide than inhaled air. The lungs are the organs from which this waste is excreted.

***Water.*** Water is eliminated from the body

- as a liquid in urine from the kidneys
- as a liquid in perspiration through the skin
- as a vapour in exhaled air from the lungs.

Urine is mostly water that the body excretes through the kidneys. Perspiration is also mainly water; it passes through the sweat pores of the skin (see figure 4.2). On very cold days a white cloud forms as we breathe out. This cloud consists of very small drops of water that have condensed from the water vapour in our warm breath. This water vapour comes from our lungs.

The presence of water vapour in the urine, perspiration and breath may be verified by using anhydrous copper sulphate, a white powder that is turned blue by water.

***Urea.*** During digestion, carbohydrates and proteins are changed into glucose and amino acids. Glucose is needed for energy and amino acids for building new tissue. These substances pass into the blood capillaries and are carried by the portal vein to the liver.

If at any time the bloodstream contains more glucose and amino acids than the body needs, some are changed into insoluble substances and stored in the liver. The main insoluble substance is glycogen. (Fat may also be formed, but this is stored in other parts of the body.) A waste product formed when amino acids are converted to glycogen is urea. Urea is soluble and is transported by the bloodstream to the kidneys, where it is removed from the blood and excreted in the urine.

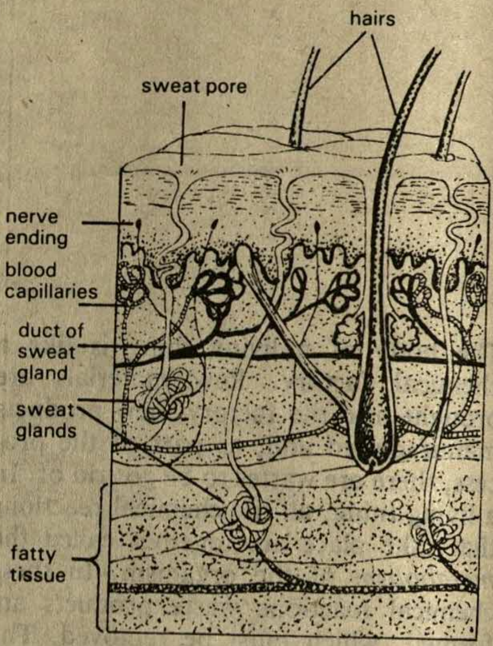


**Figure 4.2:** Section through the skin showing sweat pores and glands, hairs, nerves and blood capillaries.

***Salts.*** Sweat is a liquid composed of water, salts, urea and traces of carbon dioxide. It is secreted on the skin by sweat glands. (See figure 4.2.) When the water evaporates, deposits of salts, mainly sodium chloride, are left on the skin. No doubt you have noticed the salty taste of dried perspiration near your lips.

Sweat glands are all over the body but are concentrated in the armpits, on the

**Figure 4.3:** Monkeys searching their bodies for salt. They eat the salt, which they have sweated out.

forehead and on the palms of the hands and the soles of the feet. If we sweat excessively we may get cramps — this is why people working in hot situations need to take salt tablets. Salt is necessary to the body for it to function properly.

## Excretory organs

*The lungs.* Carbon dioxide produced by cell respiration is absorbed into the blood through the surrounding capillaries. It is carried by the blood back to the heart; this blood is then pumped to the lungs. The blood enters each lung through an artery that branches out into millions of capillaries. These come into very close contact with millions of tiny, moist air sacs connected to the outside air. (See figure 4.4.)

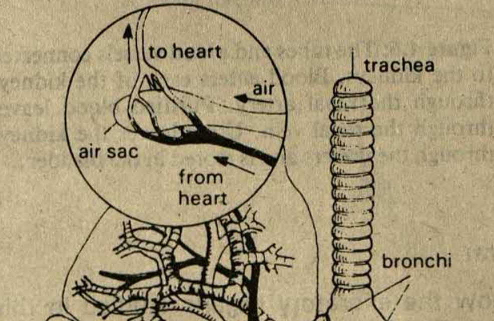


**Figure 4.4:** A lung. Air is sucked down the trachea into the bronchi and enters the millions of air sacs called alveoli. A transfer of gases occurs between the alveoli and the blood in the surrounding capillaries. The right lung, shown here, has three lobes. The smaller left lung has only two lobes — this makes room for the heart.

The carbon dioxide in the blood diffuses from the capillaries into the air sacs in the same way as the oxygen from the air in the sacs diffuses back into the capillaries. The capillaries then reunite to form a vein, which carries the blood back to the heart.

*The kidneys.* Each of us has two kidneys attached to the back wall of the abdomen, just below the diaphragm. The most important function of the kidneys is the removal of waste products, mainly urea and water, from the blood. This is done by small filtering units called nephrons. Each kidney contains about 2½ million of these tiny units. (See figure 4.5.)

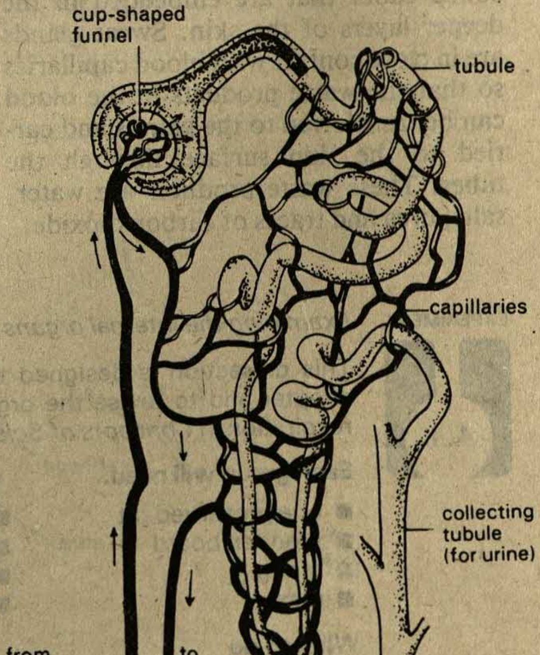


**Figure 4.5:** A nephron. Nephrons filter fluid from the blood. Useful substances in this fluid are reabsorbed into the blood before it returns to the bloodstream. The waste fluid called urine then passes out of the nephron.

The first part of the nephron, a cup-shaped funnel, filters many substances from the blood including glucose, salts, water and urea. Some of these, such as glucose and salts, are useful to the body. These useful substances are re-absorbed into the bloodstream in the second part of the nephron. The fluid that is not re-absorbed into the bloodstream is called urine. Tubes from the nephrons unite at the pelvis of the kidney to form the ureter, which carries the urine to the bladder. (See figure 4.6.) The urine is stored in the bladder and periodically discharged through the urethra.

***The skin.*** Figure 4.2 (page 32) shows a section of skin. The skin contains a large number of sweat glands. These are tiny coiled tubes that are embedded in the deeper layers of the skin. Sweat glands are in close contact with blood capillaries so that the waste products in the blood can be transferred to the glands and carried to the skin surface through the tubes. These waste products are water, salts, urea and traces of carbon dioxide.

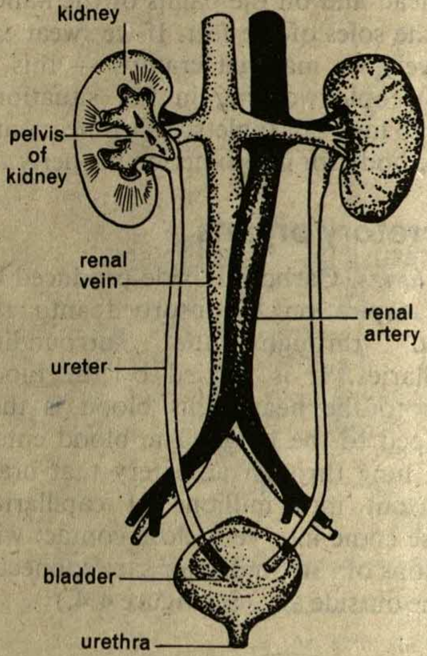


**Figure 4.6:** The tubes and blood vessels connected to the kidneys. Blood enters each of the kidneys through the renal artery. Purified blood leaves through the renal vein. Urine leaves the kidneys through the ureters and is stored in the bladder.

EXPERIMENT 4.1

### *Examining the internal organs of a rat*

This dissection is designed to show the excretory organs studied in this chapter and to revise the organs studied in the chapters on digestion and respiration in *Concepts of Science 1*.

**Each group will need:**

- one preserved rat
- wooden board
- string
- pins
- scissors
- forceps
- probe
- scalpel

**What to do**

- Purchase a preserved rat.
- Fasten the rat securely on its back on a wooden board about 60 cm x 45 cm, as shown in figure 4.7.
- Using forceps, lift the rat's skin along the dotted line shown in figure 4.7. Cut it with scissors, finishing just behind the mouth and just in front of the anus. Cut around the genitals as indicated.
- Pull the skin away from the body and pin it back to the board.

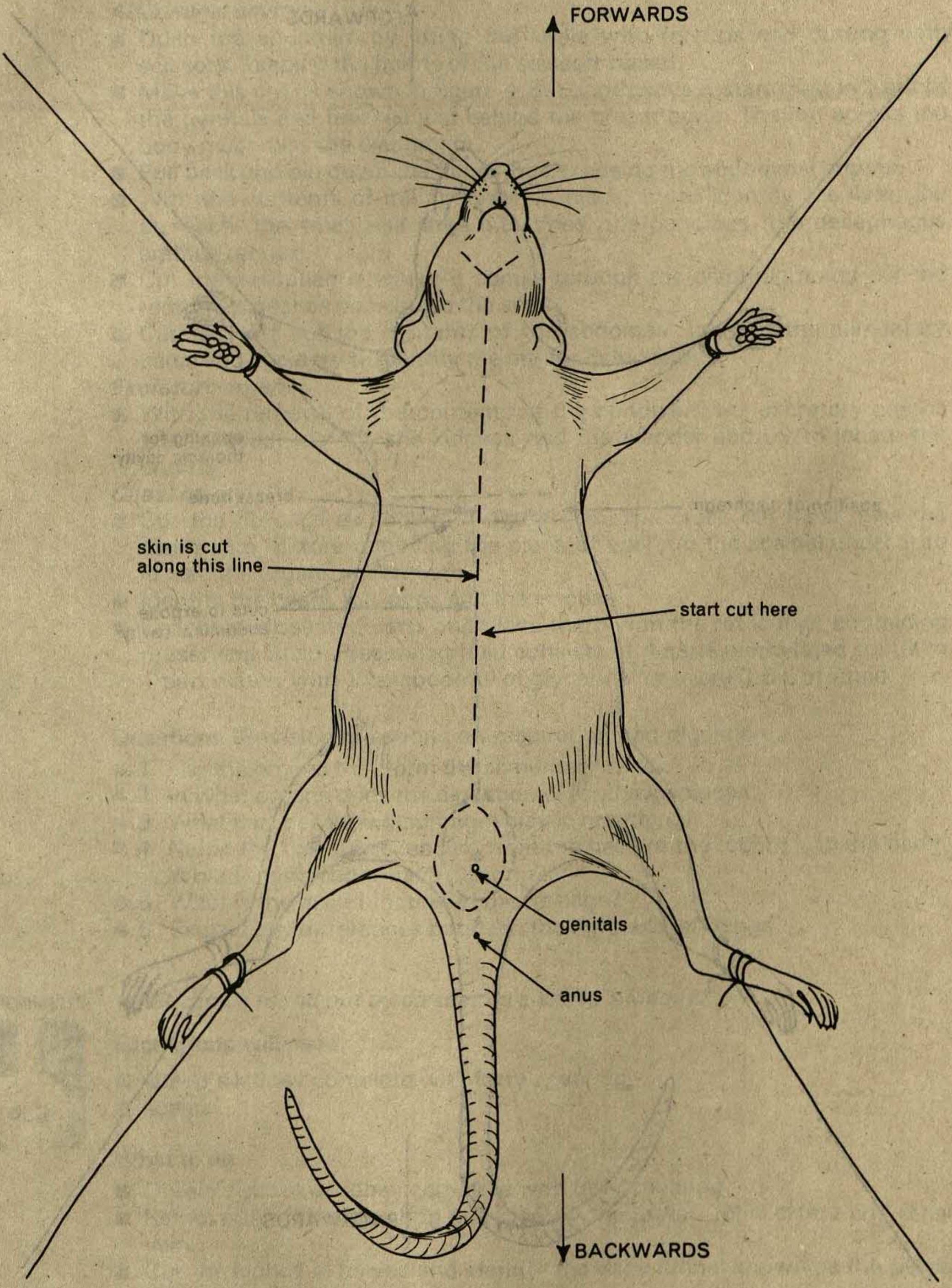


**Figure 4.7:** Preparing rat for dissection.

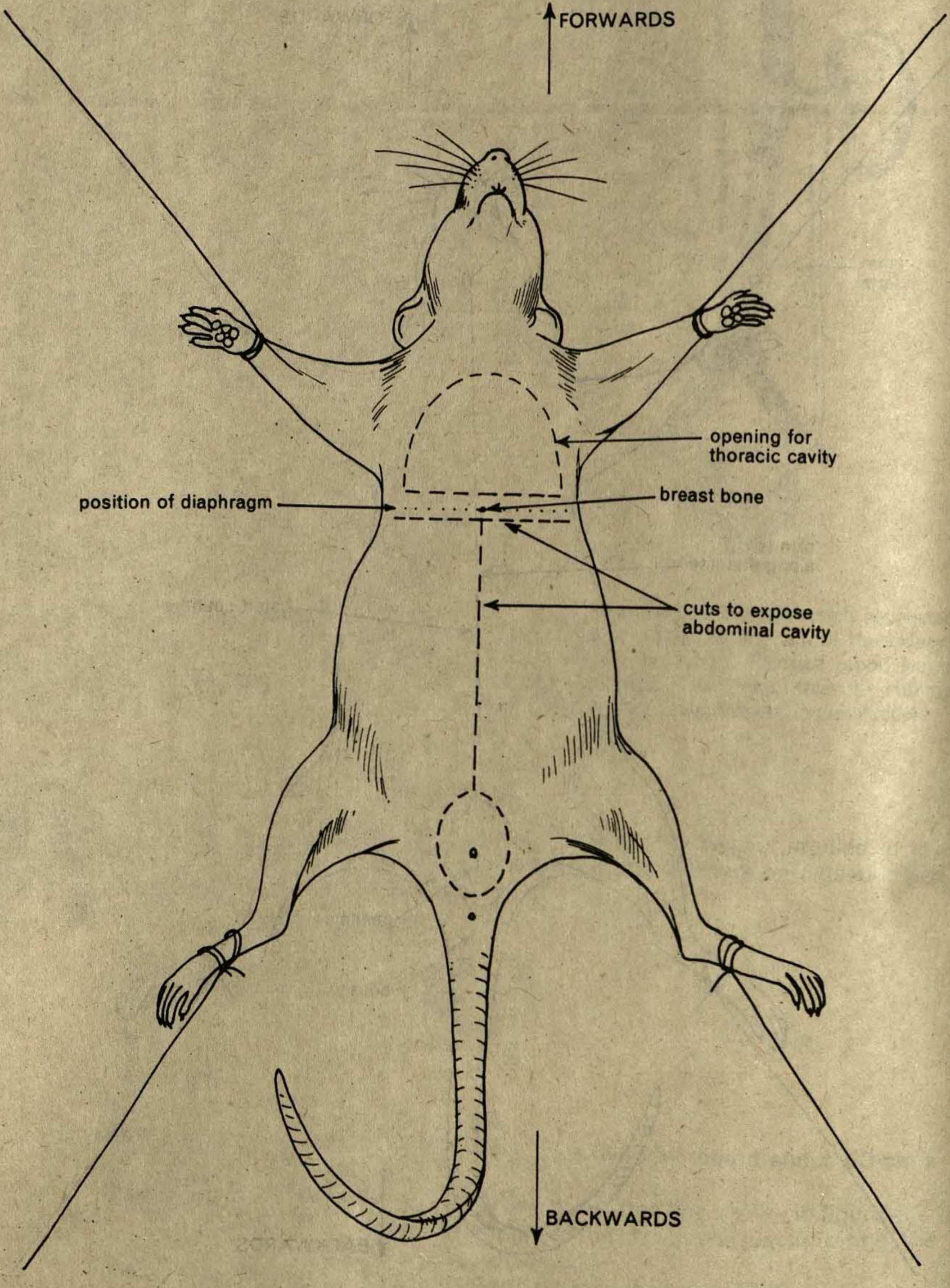


**Figure 4.8:** Cuts to expose abdomen and thoracic cavity.

### *Abdominal cavity*

- Open the abdomen by lifting the walls with forceps and cutting with scissors, keeping the points of the scissors raised.
- Make this cut as shown in figure 4.8. Lengthways it starts just in front of the genitals and finishes just behind the breast bone. The cut across the body must miss the diaphragm.
- Pull back and pin down the flaps, thus exposing the abdominal organs.
- With the contents of the abdomen in place, try to identify the liver, the stomach, the small and large intestines, the pancreas, the oesophagus and the rectum.
- Cut the oesophagus where it comes through the diaphragm and cut the rectum as near as possible to the anus.
- Carefully lift out the contents of the abdomen. Lay out the alimentary canal and again try to identify the organs listed above.

### *Excretory organs*

- With the removal of the contents of the abdomen, the excretory organs are exposed. Identify the kidneys and the bladder and try to locate the ureters.

### *Chest cavity*

- Cut the rib cage as shown in figure 4.8. The cross cut must miss the diaphragm. Before removing the piece of wall run the scalpel under it to loosen the organs underneath.
- Identify the heart, the lungs and the trachea.
- Collect all dissected parts and place them with the rat in a jar containing preserving liquid. Preserving fluid consists of 4 parts methylated spirits to 1 part water, with 1 teaspoonful of glycerine for every 0.5 L of liquid.

**Questions** (Revision questions on respiration and digestion)

**4.1** List the organs that form the alimentary canal.
**4.2** In what organs does the digestion of food take place?
**4.3** What part does the diaphragm play in breathing?
**4.4** Name the two tubes leading from the back of the mouth into the body. What function does each perform?
**4.5** What is the main function of the rib cage?
**4.6** Explain any differences between the right and left lungs.

**EXPERIMENT 4.2**

*What can be found out by dissecting a sheep's kidney?*

**Each group will need:**

- sheep's kidney complete with fatty covering
- scalpel

**What to do**

- Obtain a sheep's kidney complete with fatty covering.
- Remove the fatty covering and identify the ureter, renal artery and renal vein.
- Cut the kidney in halves and identify the wide funnel known as the pelvis of the kidney.
- Try to identify the parts of a nephron.

**Questions**

**4.7** Explain why you had no success in seeing the parts of a nephron.
**4.8** How did you distinguish between the renal artery and the renal vein?
**4.9** What is the purpose of the layers of fat around the kidney? (R)

## Excretion

1. Excretion is the removal of metabolic wastes from the body.
2. Some metabolic wastes are
    - carbon dioxide
    - water
    - urea
    - salts.
3. Organs of excretion are
    - the lungs, which excrete carbon dioxide and water
    - the kidneys, which excrete urea, water and some salts
    - the skin, which excretes water and salts.

## Spelling list

abdomen
alveoli
bronchi
diaphragm
excretion
excretory
kidney
metabolism
metabolic
nephron
secrete
urea
urethra
ureter

## Things to do

**4.10** Obtain a set of sheep's lungs from your butcher. Carefully dissect the lungs and have a close look at their structure. (Refer to figure 4.4.)
**4.11** The Australian desert is the habitat of some very interesting marsupials. Some of these animals conserve water by excreting practically no urine. Refer to your library to find out how these animals excrete urea and other wastes.
**4.12** Do fish have kidneys and a liver? Find out by obtaining an uncleaned fish from a fish shop.

## More questions

**4.13** What is meant by the term excretion? What organs of the human body are involved in excretion?
**4.14** What are the products of respiration? Where are they excreted?
**4.15** Why is it advisable to shower after physical exertion on a hot day?
**4.16** Sugar is not normally excreted from the human body. Why?

**4.17** What disease may be indicated by the presence of glucose in the urine? Try to find out how glucose can get into the urine. (R)

**4.18** What is nephritis? Find out what part of the body is affected by this disease. (R)

**4.19** People with defective kidneys may lead almost normal lives by using a kidney machine. Find out and then explain how a kidney machine works. (R)

## Test yourself (chapter 4)

Write answers to questions 1 to 4 in your workbook.

1. Name three excretory organs.
2. What waste products are excreted in your breath?
3. Name the two main waste products in the urine.
4. What does perspiration contain?

In answering questions 5 to 9, choose the best answer and write its letter in your workbook.

5. Which one of the following substances is formed as a waste product during respiration?
   (a) amino acid
   (b) urine
   (c) water
   (d) glucose.
6. As blood from the heart passes through the capillaries in a leg muscle, the muscle yields to the blood
   (a) oxygen and dissolved food
   (b) carbon dioxide and waste products
   (c) oxygen only
   (d) dissolved food only.
7. Urea is a waste product from the body that is formed
   (a) by the kidneys and then filtered from the blood
   (b) in the liver and then excreted in the kidneys
   (c) in the liver and eliminated from the bowel
   (d) during respiration in all living cells.
8. Respiration is a process that
   (a) occurs only in the lungs
   (b) occurs only in animals
   (c) releases energy from foods
   (d) makes our skin moist on hot days.
9. A cricketer who has had a strenuous time in the field on a hot day may weigh less than he did at the beginning of the day. The main reason for this is
   (a) loss of large quantities of carbon dioxide
   (b) lack of oxygen
   (c) loss of water
   (d) lack of food.

# 5

# Transfer of heat

In Book 1 it was explained that the particles of matter are in a state of rapid and irregular motion. When an object gains heat energy, the particles in it move faster. In other words, it becomes hotter and its temperature rises.

Heat energy can be passed on from one substance to another. For example, the heat in an element of an electric stove passes into a saucepan of water, causing the water to become hotter. This happens because the element is hotter than the water. If the power in the stove is switched off, the saucepan begins to lose heat to its surroundings, because they are cooler. It is a general rule that heat tends to pass from a warmer object to a cooler one.

There are three ways by which heat may be transferred from one substance to another. These are:

- conduction
- convection
- radiation.

## Conduction of heat

The saucepan of water on the stove became hotter because heat passed from the element into its metal base and from the base into the remainder of the saucepan and the water in it. In this case we say heat is being *conducted* from the element to the water.

### Conduction in solids

Conduction of heat in solids may be demonstrated by using the apparatus shown in figure 5.1. The second test tube, with no copper rod in it, is used as a control. (If we didn't use such a control, it could be said that the water was becoming hot simply because it was close to the flame.) After a minute or so, the

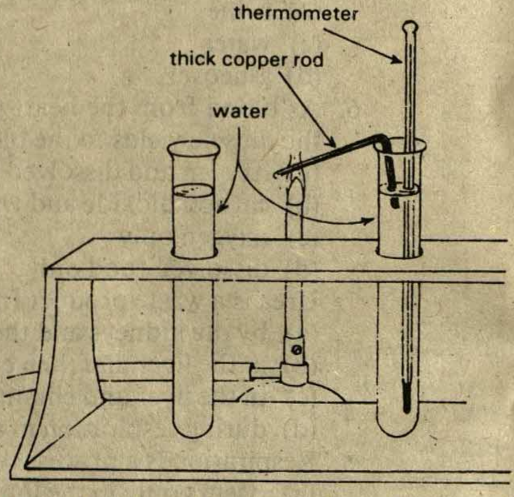


**Figure 5.1:** An experiment to show that copper is a good conductor of heat. The temperature of the water at the top of the test tube with the copper rod in it rises quite quickly. (The temperature at the bottom of this test tube does not rise very much at all. This shows that water is a poor conductor of heat.) The second test tube of water acts as a control. Without it, critics could say that it is the closeness of the flame that is causing the temperature rise in the first test tube. There is no noticeable temperature rise in the second test tube.

temperature of the water in the first test tube shows a noticeable rise. If the rod is heated long enough, the water in contact with it will boil. This experiment indicates that copper is a good conductor of heat.

Do other solids conduct heat equally well? This question may be answered by carrying out the experiment illustrated in figure 5.2. The three rods to be tested should be the same diameter. They are painted with molten paraffin wax and, when the wax has set, arranged as shown. It is best to heat gently at first, to avoid cracking the glass rod. The wax melts as heat is conducted along each rod. It is found that it melts fastest along the copper rod, not nearly as fast along the iron rod, while the glass rod shows very little conduction at all.

From this experiment we can conclude that copper is a better conductor than iron and that glass scarcely conducts heat at all. Very poor conductors, such as glass, are called insulators. If this experiment were repeated with other substances, we would find that all metals are reasonable conductors of heat, while most other solids are insulators.

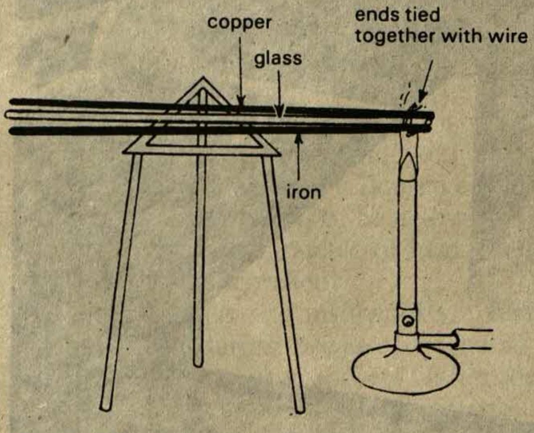


**Figure 5.2:** Comparing the rates at which heat travels along copper, glass and iron rods. Each rod is covered with wax. The wax melts quickly along the copper rod, not quite as quickly along the iron rod and hardly at all along the glass rod. Glass is an insulator.

Experiment 1.1 shows another way of comparing the conductivity of two solids.

## Uses of conductors and insulators

Saucepans, kettles and frying pans are made of metal so that heat passes into and through them quickly. Aluminium is generally used for cooking vessels because it is easy to keep clean, is light and is one of the best conductors of heat. In earlier times, before aluminium could be produced cheaply, saucepans were made of iron. However, iron is heavy and it corrodes easily. To overcome the problem of corrosion, iron saucepans were often covered with baked enamel.

Glass is used for beakers, flasks and other scientific equipment because, unlike aluminium, it is not attacked by acids and other chemicals. It is also transparent, which is another advantage. The fact that glass is an insulator is not a serious disadvantage provided the glass is thin.

The handles of saucepans, kettles, etc., are usually made of plastic, because plastic is an insulator. We handle hot dishes with an oven cloth because cloth also is an insulator.

Aluminium cups will never be popular for drinking hot coffee or tea. Heat is conducted from all over the cup to the part that touches the lips. This is why an aluminium cup seems hotter than a china cup. Have you ever paused to notice that the hot coffee that we sip does not feel too hot provided it doesn't touch our lips? The insides of our mouths, therefore, must be less sensitive to heat than our lips are.

Soldering irons are made of copper, not of iron as the name implies. Copper is a better conductor than iron and the heat flows quickly from the hot "bit" to the joint being soldered. Another advantage of copper is that it can be plated with solder much more easily than iron can.

## The sense of touch in judging temperature

The sense of touch is not a good judge of temperature. For example, a piece of iron exposed to the sun feels much hotter than a piece of wood also in the sun, even though both are at the same temperature. Because it is a good conductor, the iron conducts much more heat to the fingers than the wood does. It is this extra flow of heat that causes us to think the iron is at a higher temperature. The reverse is true on a cold morning. On such a morning, iron feels colder than wood because more heat is conducted out of your hand by the iron than by the wood.

## Conduction in liquids

Figure 5.4 is a drawing of an experiment designed to show that water is a poor conductor of heat. The steel wool is used to prevent the ice from floating to the top of the test tube. Even though the water is boiling at the top, the ice melts very slowly and the test tube can be held comfortably at the bottom. This experi-

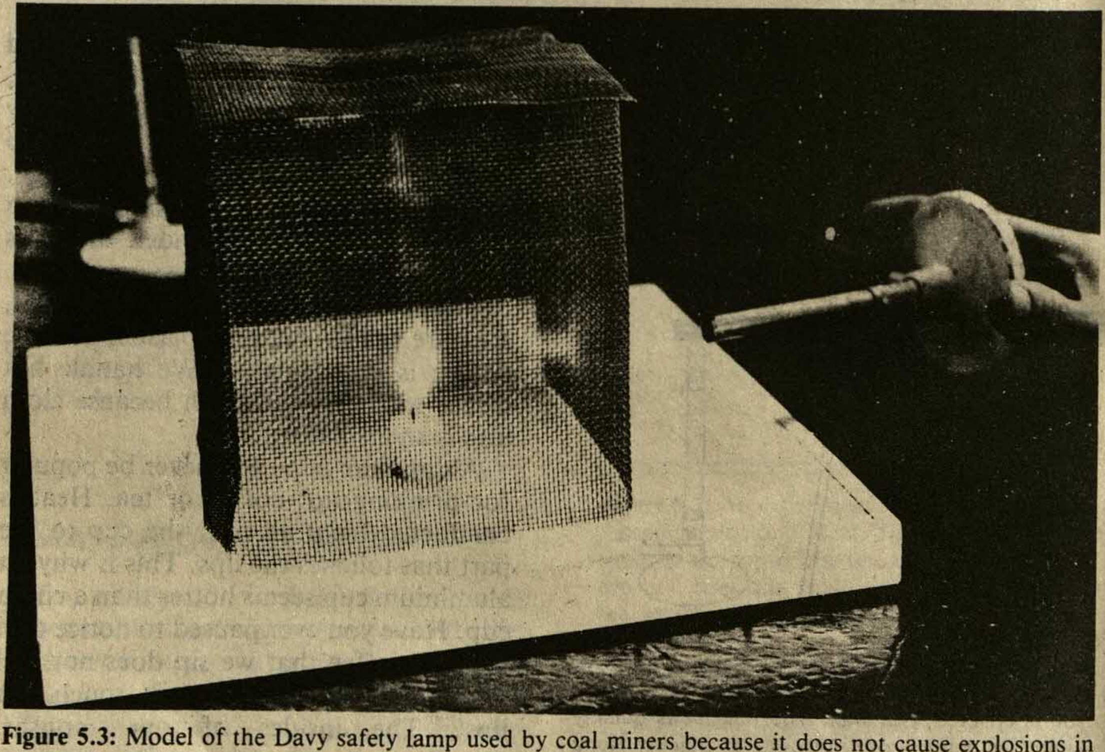


**Figure 5.3:** Model of the Davy safety lamp used by coal miners because it does not cause explosions in mines. The copper mesh surrounding the flame conducts heat away from any hot spot, so that flammable gas outside the lamp never gets hot enough to ignite.

ment also verifies that glass is a poor conductor of heat. It could not be done with a copper test tube, for example.

Many experiments have been performed to test the conductivity of other liquids. All have indicated that liquids in general are poor conductors. One obvious exception is mercury. This is because mercury is a metal — one of the few that is a liquid at room temperature.

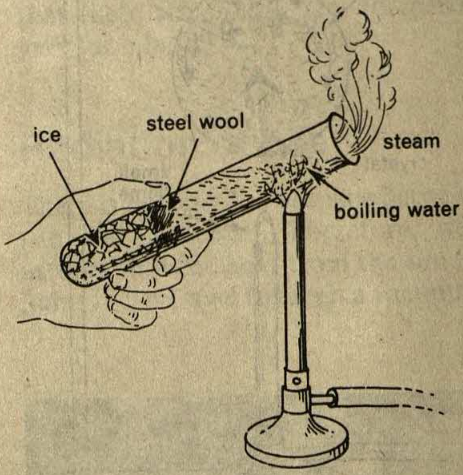


**Figure 5.4:** Water is a poor conductor of heat.

## Conduction in gases

Gases are poor conductors of heat. The fact that air is a very good insulator may be demonstrated in a number of ways. For example, you can hold your hand quite close to the side of a Bunsen burner flame without any fear of being burnt. If air were a good conductor of heat, your hand would be scorched.

Foam plastics and insulwool are very effective insulators because of the air trapped in the empty pockets within the material. These materials are used extensively for insulating houses, refrigerators and ovens. Down sleeping bags and quilts are another example of the insulating properties of trapped air. The feathers, especially if they are fluffed-up, can trap quite a lot of air. This air acts as an insulating barrier that prevents heat from being conducted away from the body. The bodies of birds are insulated in the same way.

## Conductivity explained

The particle theory can be used to explain the conduction of heat. According to this theory the particles of a substance vibrate more rapidly when the substance is heated. Particles next to the heated ones are then bumped and set in motion. These, in turn, set the next lot in motion and heat is thus conducted from the heated end to the other end of the substance.

Metals are the best conductors. The particles in metals are generally packed very closely together. Therefore it is easy for a vibrating particle in a metal to pass on some of its energy to a neighbour.

Gases are the poorest conductors of heat. In gases the particles are widely spaced. Therefore there is less chance of energy being passed between particles.

It is interesting to note that metals are also good conductors of electricity. The conduction of electricity, however, is different from the conduction of heat.

**Table 5.1:** Conductors and insulators

| Conductors | Insulators |
|---|---|
| silver (the best)<br>copper<br>gold<br>aluminium<br>graphite<br>mercury<br>iron<br>tin<br>lead<br>stainless steel | air and other gases (the best)<br>straw } trapped air<br>glass wool } trapped air<br>wool } trapped air<br>plastics<br>dry pine wood<br>asbestos<br>rubber<br>water<br>glass |

## Convection

When a large fire is burning on a calm day, a cloud of sparks and smoke rises almost vertically. It is very much hotter above the fire than it is the same distance out from it sideways. Air is heated by the fire and rises, carrying the heat with it. This form of heat transfer is called convection.

The setting up of convection currents in water may be demonstrated by using the apparatus shown in figure 5.5. A crystal of Condy's crystals is dropped into the flask and begins to dissolve. When the water at the bottom of the flask is heated, convection currents are set up. These are shown by the movement of the colour from the purple crystal. (See figure 5.5.)

The formation of these currents may be explained as follows. The heated water expands and becomes less dense. Colder (and therefore denser) water surrounding it pushes it up as though it were a piece of wood. This colder water is then heated in its turn and thus the currents are set up.

One application of this is in the electric hot water jug. The heating element is placed at the bottom so that convection currents are set up and all the water is heated. If the element were placed at the top, the water at the bottom could remain cold even though that at the top was boiling.

From the examples given it can be seen that convection currents could not be set up in solids; they can be set up only in fluids.

## Sea breezes

Have you ever visited the coast during summer and noticed how calm it is in the morning and how windy in the afternoon? These afternoon sea breezes are usually caused by convection. (See figure 5.6.)

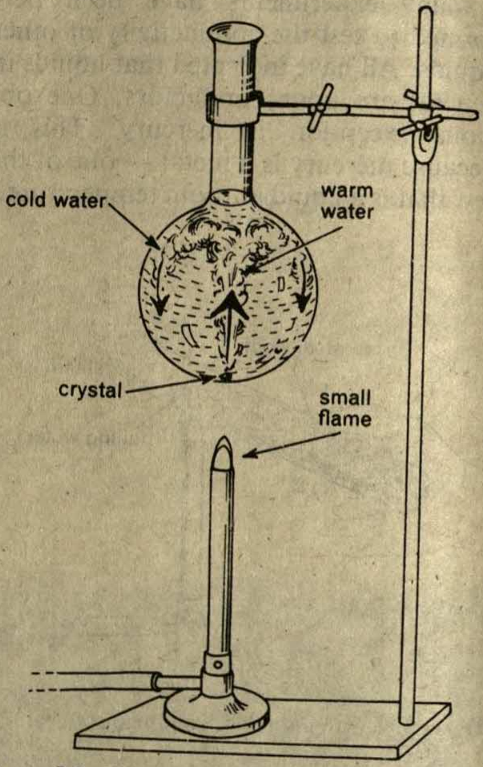


**Figure 5.5:** Convection currents in water. As the cold water settles down, the warm water is forced up, carrying the colour with it.

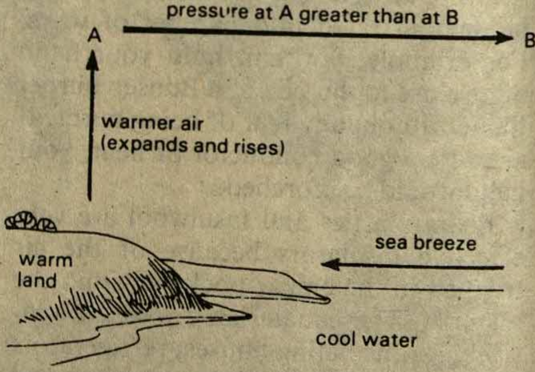

pressure at A greater than at B
A
B
warmer air (expands and rises)
sea breeze
warm land
cool water

**Figure 5.6:** The formation of a sea breeze on a hot summer afternoon. Air pressure over the land becomes less than the air pressure over the sea. This causes an air flow from the sea to the land.

The land heats up more rapidly than the ocean. Therefore, air in contact with the land becomes hotter than air in contact with the water. We know that hot air rises if it is adjacent to colder, heavier air. The cold air over the water flows in to take the place of the hot air over the land. This cold air in its turn is heated, and so a cycle is set up that becomes apparent as a breeze off the sea. Why is it that these sea breezes do not penetrate very far inland?

## Radiation of heat

There is nothing in the space between the sun and the earth. Therefore, we can assume that the heat from the sun is like light: it can travel through a vacuum.

This kind of heat movement must be different from both conduction and convection. Both these methods require substances to carry the heat, whereas heat from the sun requires nothing to carry it. This third method is called radiation and the heat is called radiant heat.

Radiant heat and light are similar in other ways. If a cloud passes over the sun, a lot of light is cut off and it becomes duller. At the same time it becomes cooler, indicating that heat is also cut off. Radiant heat and light must therefore travel at the same speed.

Focusing light from the sun through a lens onto a sheet of paper soon causes the paper to smoulder at the point of focus. This indicates that the lens has focused the heat as well as the light.

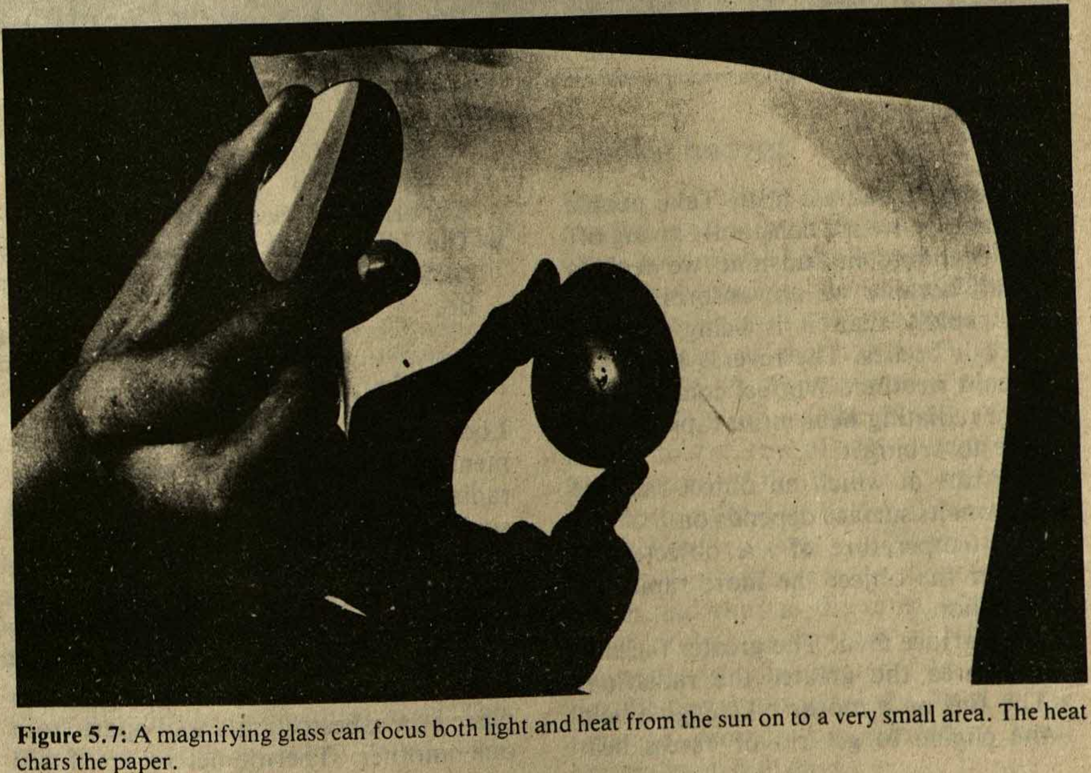


**Figure 5.7:** A magnifying glass can focus both light and heat from the sun on to a very small area. The heat chars the paper.

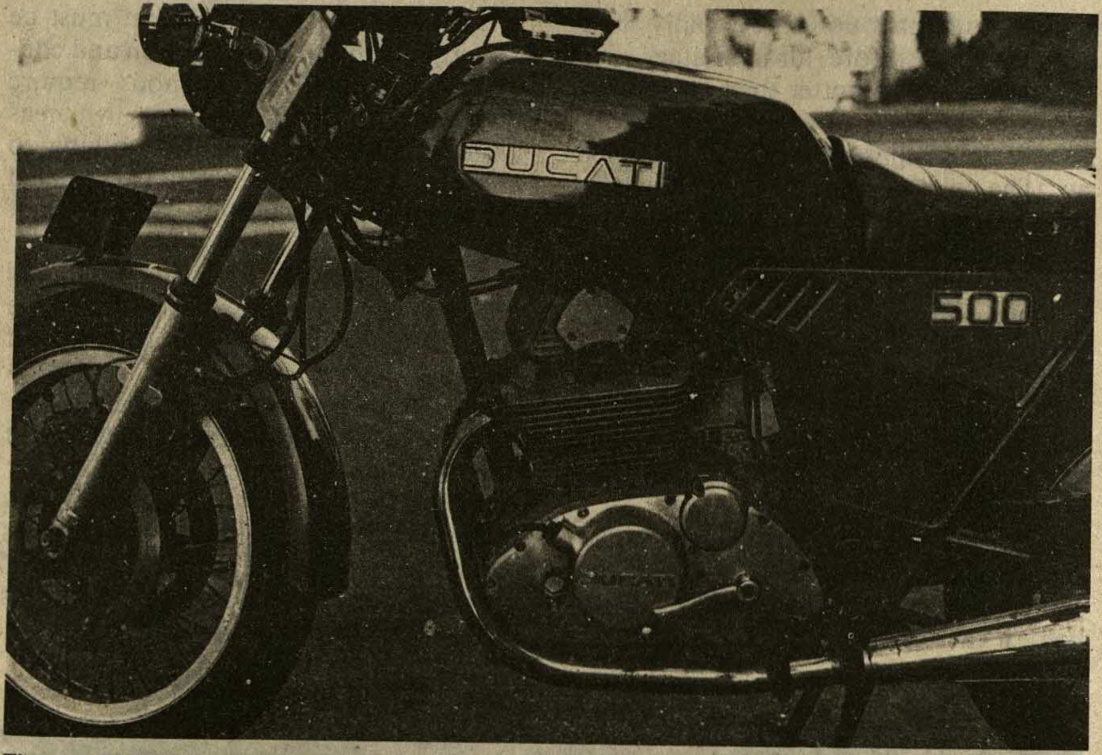


**Figure 5.8:** The fins on the engine of a motor bike increase the surface area of the engine block considerably. This gives the engine a greater area from which to radiate excess heat.

All objects radiate heat. Take people for example: we are constantly giving off heat. Standing in sunshine we feel its warmth because we are absorbing heat more rapidly than it is being radiated from our bodies. The reverse applies in dull cold weather. We feel cold because we are radiating heat more rapidly than we are absorbing it.

The rate at which an object radiates heat from its surface depends on

- The temperature of the object. The hotter the object the more rapid the radiation.
- The surface area. The greater the surface area the greater the radiation. The fins on a motor bike engine help the engine to get rid of excess heat more rapidly. (See figure 5.8.)
- The kind of surface. Some surfaces radiate heat more rapidly than others do.

## Radiating surfaces

Look at figure 5.9. It shows an experiment designed to find out which surface radiates heat more rapidly — a shiny tin surface or a dull black surface.

Two small tin cans are selected. One is painted a dull black and the other is left shiny. Flat pieces of cardboard with holes in the centre are used as lids. The cans are filled with boiling water and placed on asbestos mats well apart from one another. Thermometers are fitted through the lids and held in place by corks. (See figure 5.9.) The bulbs of the thermometers should be at about half the full depth of the water. The temperature of the water in each can is read every minute for about 20 minutes. Even before the 20 minutes is reached it will be noticed that the dull black can is radiating heat more rapidly than the shiny can. Dull black surfaces must therefore be better radiators of heat than silvery surfaces.

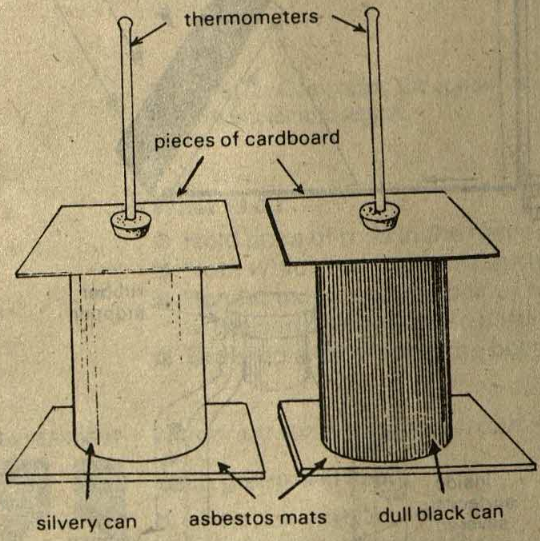


**Figure 5.9:** Cooling by radiation. The hot water in the dull black can cools more rapidly than the water in the silvery can.

## Absorption of radiant heat

If we place a sheet of iron in front of an electric radiator, the heat is cut off from us immediately. Radiant heat apparently does not travel through the iron. After some time, however, the iron becomes hot and begins to radiate heat itself. The iron has evidently absorbed radiant heat from the radiator.

Some surfaces absorb radiant heat more rapidly than others. The following experiment illustrates this. Two similar thermometers are placed on a bench in sunlight. A piece of black cloth is placed over one bulb and a piece of white cloth over the other. After ten minutes the temperature recorded by the thermometer under the black cloth is noticeably higher than the other. This shows us that *black surfaces absorb heat more rapidly than white surfaces do*.

Many everyday observations support this. For example, black motor cars are hotter in summer than white motor cars. Tarred roads are hotter in summer than concrete roads for the same reason.

Heat that is not absorbed by a surface must be reflected back off it. Therefore, *white surfaces reflect heat more than black surfaces do*. For this reason, many houses are lined with aluminium foil to keep them cooler in summer.

## A solar heater

Figure 5.10 shows how a solar heater may be used to provide a supply of hot water to a home. The heater itself is a thin copper tank painted a dull black. It should be set up so that it faces north, and inclined so that the sun's rays at noon strike it approximately at right angles. The top of the heater is connected to the top of the storage tank. The bottom of the tank is connected to the bottom of the heater. This allows convection currents to form in the system. Hot water rises to the top of the heater and runs to the tank, while cold water from the bottom of the tank descends to the heater. An electric heating element is generally fitted to the tank to provide supplementary heat, especially on dull days.

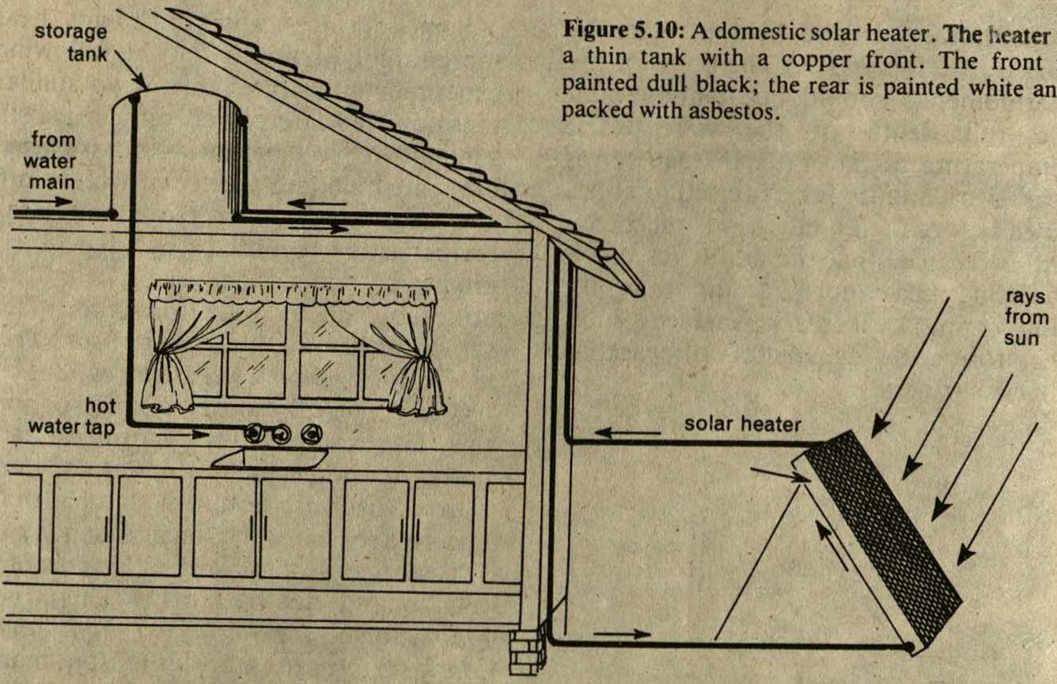


**Figure 5.10:** A domestic solar heater. The heater is a thin tank with a copper front. The front is painted dull black; the rear is painted white and packed with asbestos.

## The vacuum flask

The vacuum flask is widely used for keeping cold liquids cold, or hot liquids hot. One is illustrated in figure 5.11. It consists of a double-walled glass vessel, with the space between the walls emptied of air. This means that heat cannot be conducted across from one wall to the other. The surfaces of the glass in the cavity are silvered. This reduces radiation of heat, either into or out of the flask. Keeping the flask stoppered prevents convection currents being set up between the inside of the flask and the air outside.

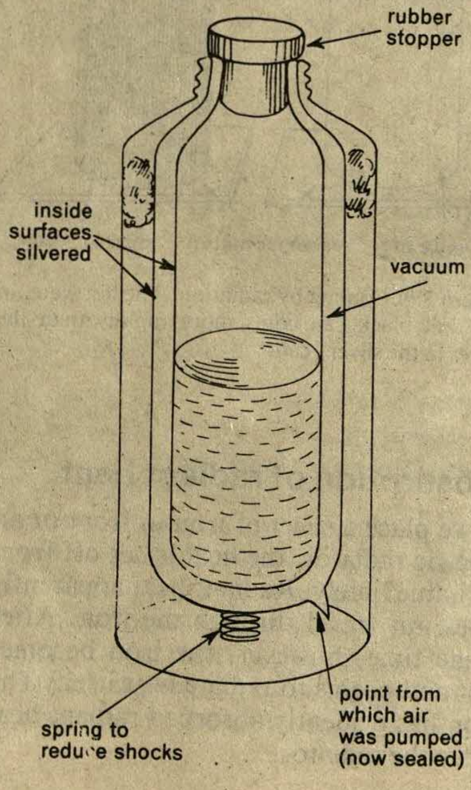


**Figure 5.11:** The vacuum flask. The vacuum prevents transfer of heat by conduction. The silvered surfaces reduce loss of heat by radiation.

**EXPERIMENT 5.1**

## *Comparing the conductivities of two metals*

**Each group will need:**

- 10–cm lengths of copper, iron, glass, and stainless steel rods, all about 5 mm in diameter
- Bunsen burner

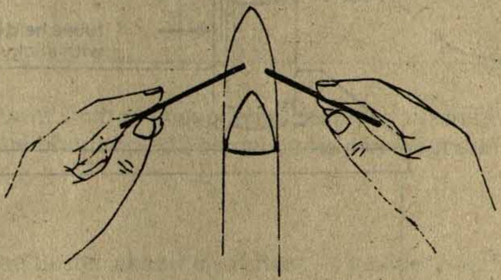


**Figure 5.12:** Comparing the conductivity of two metals. The pieces of wire should have the same diameter and length.

**What to do**

- Hold pairs of rods in the flame, one in each hand, as shown in figure 5.12.
- Note which rod becomes the hotter.
- Repeat using another pair of rods. Make sure the rods are at approximately the same temperature before you begin the test.
- Draw up a list placing the best conductor first and the poorest last.

**EXPERIMENT 5.2**

## *Demonstrating convection currents in air*

**Each group will need:**

- shoe box with lid
- cardboard tube about 3 cm in diameter
- candle
- dry rag
- scissors
- Sellotape
- Bunsen burner

**What to do**

- Set up the apparatus as shown in figure 5.13. Cut two circular holes in the lid of the box, each a little smaller than the diameter of the cardboard tube.
- Cut the cardboard tube in two and fix the two pieces in position with Sellotape.
- Place a candle beneath one of the tubes, light it and replace the lid.
- Screw up the rag and light it in a Bunsen flame. When it is smouldering, hold it above the tube with no candle below it.
- Watch the direction of movement of smoke at the tops of both tubes.

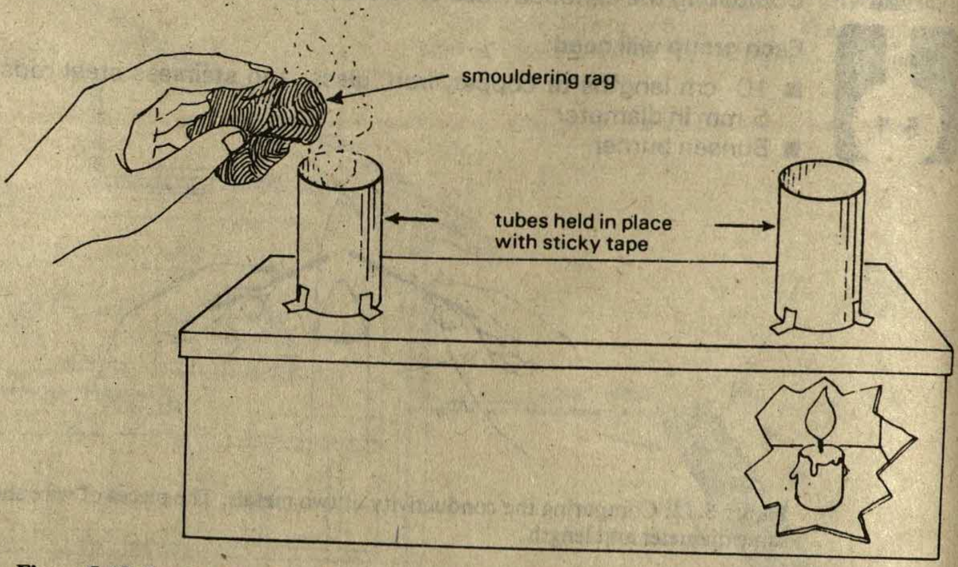


**Figure 5.13:** Setting up convection currents in a cardboard box using a candle flame.

**Questions**

**5.1** Does figure 5.13 agree with what you saw happening? Draw a diagram showing the direction of air currents through the system.

**5.2** Explain how the air currents were set going.

### EXPERIMENT 5.3

*Which surface is the better absorber of heat — dull black or silvery?*

**Each group will need:**

- two small cans, such as baby-food cans
- two pieces of cardboard for lids
- two corks
- cork borers
- two thermometers
- two asbestos mats
- 100 watt bulb in socket

**What to do**

- Paint the outside of one of the cans a dull black and leave it to dry.
- Fill both cans with cold water from the same tap.
- Place the cans on asbestos mats either side of the bulb.
- Fit the thermometers as indicated in figure 5.8. Record the temperatures and switch on the globe.
- Record the temperature on each thermometer every minute for about 20 minutes.

- Tabulate your results as follows:

| Time (min.) | 0 | 1 | 2 | |
|---|---|---|---|---|
| Temperature of silvery can | | | | |
| Temperature of black can | | | | |

*Note:* If a 100 watt bulb is unavailable, suitable alternatives would be a bar radiator or a piece of crumpled iron gauze held in a Bunsen flame.

**Questions**

**5.3** Which is the better absorber of heat — a silvery surface or a dull black surface?

**5.4** Which road surface is hotter on a sunny day — bitumen or concrete?

**5.5** Which clothes would be cooler on a hot day — black or white? Explain.

**EXPERIMENT**

**5.4**

### *Does clear glass absorb radiant heat?*

**Each group will need:**

- two thermometers
- bar radiator (optional)
- thick glass slab
- three retort stands with clamps

**What to do**

- This experiment may be carried out in sunshine or in front of an electric radiator.
- Fix identical thermometers so that they are parallel to one another and, if a radiator is used, equidistant from the heating element. See that the bulbs have plenty of air around them.
- Place a thick glass slab in front of the bulb of one of the thermometers.
- Record the temperature on the two thermometers every three minutes for fifteen minutes.

**Questions**

**5.6** What did you find out about the rises in temperature on the two thermometers?

**5.7** Does glass absorb radiant heat?

**5.8** If heat is absorbed by the glass, what do you think happens to it?

## Transfer of heat

1. *Conduction.* The heat energy is passed on from one particle to the next; each particle merely vibrates about the one position. Metals are the best conductors.
2. *Convection.* The particles move, carrying the heat with them. Convection can only take place in fluids.
3. *Radiation.* No material is necessary to carry radiant heat; it travels best through a vacuum. Black surfaces are the best absorbers and best radiators of heat.

## Spelling list

absorber
absorption
aluminium
asbestos
conduction
conductor
convection
corrode
descend
equidistant
noticeable
paraffin
radiant
radiation
smoulder
thermometer
transparent
vacuum

## Things to do

**5.9** Wrap one layer of paper tightly around a copper rod. Hold the rod in a flame. Can you explain why the paper does not burn?

**5.10** Boil some water in a cardboard drinking cup. Stand the cup on gauze on a tripod. Why doesn't the cardboard burn through?

**5.11** Make a model solar heater by using a concave mirror to focus the sun's rays on some water in a test tube. Place a piece of darkened copper in the water as an absorber of the sun's heat.

**5.12** Compare the insulating qualities of (a) cotton wool, (b) aluminium foil and (c) cotton wool surrounded by aluminium foil. Use three thermometers. Expose them to sunshine with each bulb surrounded by one of the materials to be tested.

**5.13** In your library, read about the miners' safety lamp invented by Sir Humphry Davy. Make a model of one such lamp, as shown in figure 5.3. Direct a stream of bench gas sideways into the gauze box. Why does the gas burn only inside the gauze? Why would such a lamp be safer in a coal mine than a naked flame?

## More questions

**5.14** Name three good conductors of heat, and three insulators.
**5.15** Which would melt more quickly in sunshine — a plain white icecream or a chocolate-coated icecream? Why?
**5.16** Why do birds sometimes fluff out their feathers on a cold morning?
**5.17** Discuss the two main advantages of light-coloured cars over dark ones.
**5.18** Why are saucepans with specially ground flat bottoms best for electric stoves?
**5.19** Why would a single blanket not be as warm as two blankets each half the thickness of the single one?
**5.20** Lino feels colder to the bare feet on a winter's morning than carpet. Why?
**5.21** Why is a downstairs flat cooler in summer than an upstairs flat?
**5.22** Which would be the more efficient refrigerator — a horizontal one with the lid opening vertically or the usual vertical type with the door opening sideways? Explain.
**5.23** Explain why gas ovens have the burners at the bottom while some electric ovens have the heating elements both top and bottom.
**5.24** Why would it be dangerous for an aircraft doing stunt flying on a hot day to fly low down across a beach straight out to sea?
**5.25** Why is it often colder on a clear winter's night than on a cloudy night?

## Test yourself (chapter 5)

Write the answers to questions 1 to 5 in your workbook. Answer each question with a single word selected from the list on the right.

1. The best conductor of heat: ____________
2. The best insulator: ____________
3. The best radiating surface: ____________
4. The best absorbing surface: ____________
5. The best reflecting surface: ____________

iron
copper
air
wool
wood
black
silvery

In answering questions 6 to 9, choose the best answer and write its letter in your workbook.

6. Of the pairs of substances listed below, the pair containing only good conductors of heat is
   (a) wood and iron
   (b) iron and glass
   (c) tin and nickel
   (d) tin and glass.

7. A feather-filled quilt keeps a person warm in bed because:
   (a) Feathers are good insulators.
   (b) A feather quilt has very little weight.
   (c) A lot of air is trapped in a feather quilt.
   (d) Feathers are easily fluffed up.
8. A building is heated by a hot-water system feeding hot water through a number of radiators. The most efficient colour for these radiators would be
   (a) silver
   (b) cream
   (c) brown
   (d) black.
9. Which one of the following is the best explanation for the way convection currents may be set up in air?
   (a) When air is heated, it expands and rises.
   (b) Cold heavy air sinks and pushes up warm light air.
   (c) When air is heated it tends to be pushed upwards.
   (d) Air rises over hot areas and sinks over cold areas.

# 6

# Metals and non-metals

Hundreds of years ago it was thought that everything on earth was made up of one or more of four "elements". These elements were fire, air, earth and water. Copper, for example, was thought to contain earth and fire. The shine of polished copper was due to the fire in it.

Men then began to experiment in laboratories. They made many new substances. They tried to explain that these substances were made of fire, air, earth and water but experiments proved them wrong. Thus they were forced to discard the four-element theory and propose new theories about elements.

Today we define an element as a simple substance that cannot be made simpler. Ninety-two such elements have been found in nature; they range from hydrogen with the lightest atoms to uranium with the heaviest. About seventy of these elements are metals; the remainder are non-metals. The non-metals include solids such as carbon and phosphorus, one liquid called bromine and a number of gases such as oxygen and nitrogen.

## What is a metal?

Iron is a metal. We know it is a metal because:

- It is *lustrous*; a fresh surface is shiny.

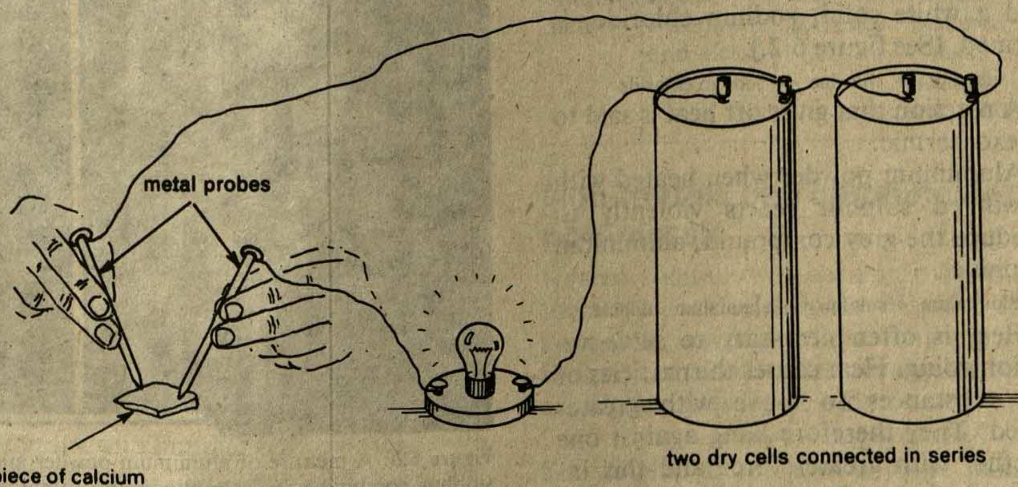


**Figure 6.1:** The metal calcium is a conductor of electricity.

- It is *malleable*; it can be beaten out into sheets.
- It is *tough*; an iron anchor chain, for example, is very strong.
- It is *heavy*.
- It is a *good conductor* of heat and electricity.

Sulphur is a non-metal. It does not shine, it is brittle, it is light and it conducts neither heat nor electricity.

Experiment 6.1 tests galena to find out whether it is a metal.

Scientists have named metals discovered in the last two centuries with words ending in "ium". Sodium, aluminium, magnesium, calcium, radium and uranium are examples. Helium is an exception to this method of naming — it is not a metal but a gas.

## Metals can combine with non-metals

Metals generally can be made to combine with non-metals. A piece of the metal sodium, if first heated in a small spoon, will combine vigorously with the gas chlorine. A lot of heat energy is given off and a white solid, sodium chloride, is formed. (See figure 6.2.)

sodium + chlorine → sodium chloride

A reaction that gives off heat is said to be exothermic.

Aluminium powder when heated with powdered sulphur reacts violently to produce the grey compound, aluminium sulphide.

aluminium + sulphur → aluminium sulphide

Heat is often necessary to set a reaction going. Heat causes the particles of the substances to move with greater speed. They therefore bang against one another with greater force and this increases their chances of combining

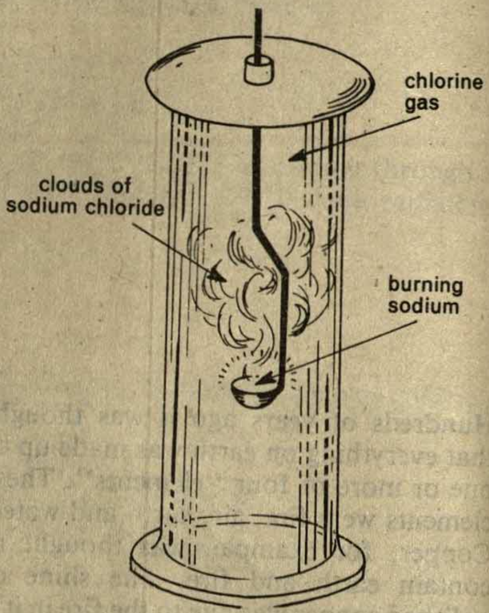


**Figure 6.2:** Sodium burning in chlorine to form white clouds of the salt sodium chloride.

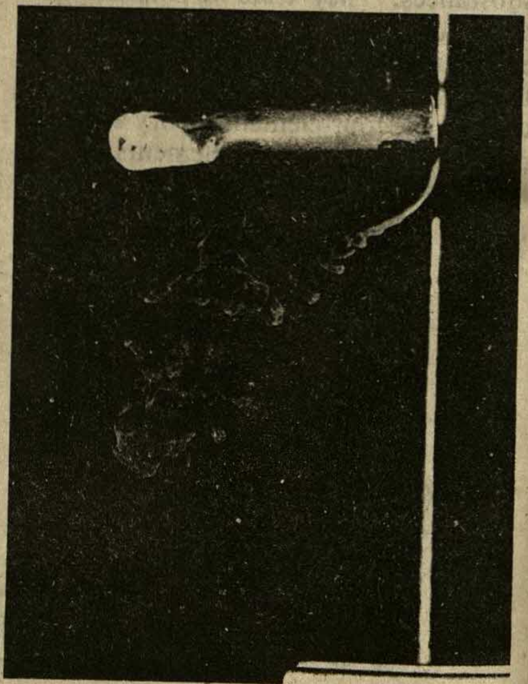


**Figure 6.3:** A mixture of aluminium powder and sulphur combining to form aluminium sulphide. Note that the test tube is white hot.

chemically. Once the reaction is started, the heat given off is often sufficient to keep it going. The two reactions already considered are good examples of this; so is the burning of magnesium in oxygen.

magnesium + oxygen → magnesium oxide

Notice that the names of the compounds formed in these reactions have the suffix "ide". This is common practice when naming compounds of two elements. A carbide, for example, is a compound of two elements one of which is carbon. Calcium carbide would therefore contain the elements calcium and carbon. Can you name the elements in each of the following compounds — magnesium nitride, sodium fluoride, potassium bromide and iron phosphide?

## Some metals corrode more readily than others

Sodium is a dangerous metal to handle. It reacts violently with water and quickly with air. Because of these reactions, sodium must be stored in kerosene. Kerosene does not react with sodium and therefore provides good protection against corrosion.

Iron is another metal that corrodes rather readily in air, particularly if it is damp. It reacts much more slowly than sodium, but nevertheless the rusting of iron is a problem. Like sodium, iron may be protected by covering it with kerosene. However, most iron objects that need to be protected are either covered with paint or plated with another metal such as chromium or nickel. These metals do not corrode in air and are used for protecting such things as toasters, irons, reflectors of radiators, and bumper bars on cars.

Other metals that do not corrode in air are silver, gold and platinum.

## Alloys: metals with metals

When pieces of lead and tin are heated together in a crucible, the two metals melt and mix. The mixture looks very much like the original metals. There is no evidence of any chemical change.

Mixtures of metals are called alloys. The alloy of lead and tin is called solder. Solder melts at quite low temperatures and is used for sealing the joints in tins and joining wires in radio and TV sets. Table 6.1 gives information on some well known alloys.

**Table 6.1:** Alloys

| Alloy | Metals present | Special properties | Uses |
|---|---|---|---|
| solder | lead and tin | low melting point | joining pieces of metal |
| brass | copper and zinc | does not corrode; stronger than either copper or zinc | electrical fittings |
| stainless steel | iron, chromium and nickel | does not corrode | cutlery, kitchen ware, railway carriages |

## Non-metals can combine with non-metals

Heated sulphur will burn in oxygen to form a gas called sulphur dioxide. The apparatus used for the burning of sodium can also be used for the burning of sulphur. (See figure 6.2.)

sulphur + oxygen → sulphur dioxide

The sulphur burns with a violet flame; sulphur dioxide is a choking gas.

Chlorine combines with hot carbon to form carbon tetrachloride, a compound used in some fire extinguishers.

Nitrogen can be made to combine with hydrogen to form ammonia. Ammonia is used for making nitric acid, fertilizers, explosives and plastics.

Although carbon tetrachloride and ammonia are prepared in large quantities industrially, they are hard to make in small quantities in the laboratory.

## Oxides and water

To test the products of these reactions we need an indicator to distinguish between acids and alkalis. Such an indicator is litmus, which is red in acid solutions and blue in alkaline solutions.

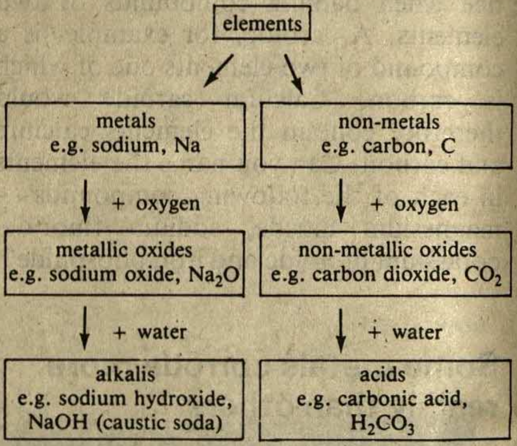
Three metals, sodium, calcium and magnesium, are burnt separately in air. Each oxide formed is tipped separately into a little water in a test tube. After shaking, pieces of red and blue litmus paper are added. In each case the red litmus turns blue while the blue is unchanged. This indicates the presence of alkalis. Therefore when metallic oxides dissolve in water they form alkalis.

Some metals, such as iron and copper, burn in air to form oxides that are insoluble in water. There is therefore no reaction with litmus. (See experiment 6.3.) Other metals, such as gold, do not burn at all when heated in air.

We test the oxides of non-metals in the same way as we test the oxides of metals. Three non-metals, carbon, sulphur and phosphorus, are heated in spoons and set alight. The spoons are placed in gas jars containing a little water, as shown in figure 6.4. When pieces of red and blue litmus paper are added to the water and shaken, the red paper remains unchanged and the blue turns red. This indicates that the oxides formed by burning have dissolved in the water and that the solutions are acidic. We may therefore conclude that oxides of non-metals, when dissolved in water, form acids.

As in the case of the metals, there are a number of non-metals that do not form oxides when heated in air.

**Table 6.2:** Reaction of oxides with water



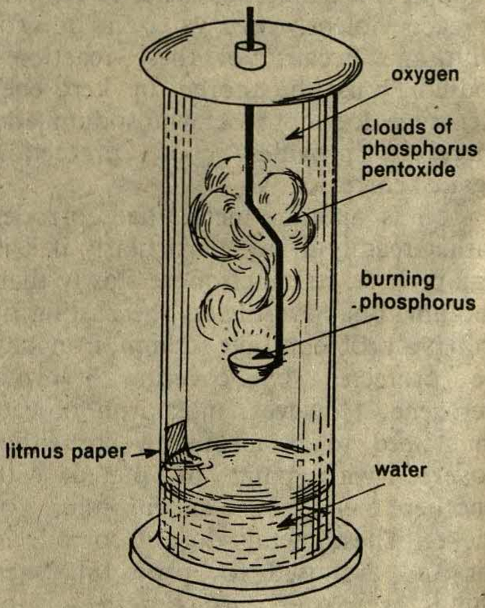


**Figure 6.4:** Phosphorus burns in oxygen to form clouds of the white solid phosphorus pentoxide. Phosphorus pentoxide dissolves in water to form phosphoric acid.

**EXPERIMENT 6.1**

## *Is galena a metal?*

**Each group will need:**

- pieces of galena
- apparatus for testing conductivity (see figure 6.1)
- hammer

**What to do**

- Carry out tests for the various properties listed on page 55, to find out whether galena is a metal.
- Copy the table below and use it to record the results of your tests.

| Test | Result |
|---|---|
| 1. Is galena shiny? | |
| 2. Can it be beaten into a sheet? | |
| 3. Is it tough or is it brittle? | |
| 4. Is it heavy? | |
| 5. Is it a conductor of electricity? | |

**Question**

**6.1** What is your conclusion? Is galena a metal?

**EXPERIMENT 6.2**

## *Testing oxides to see whether they are acidic or alkaline*

**Each group will need:**

- small piece of magnesium ribbon
- small quantity of sulphur
- red and blue litmus paper
- tongs
- Bunsen burner
- deflagrating spoon
- gas jar and cover slip

**What to do**

- Hold the magnesium in a pair of tongs and set it alight by placing it in a Bunsen flame. Avoid looking directly at the magnesium as it burns. Allow the ash to fall on a piece of paper.
- Moisten pieces of red and blue litmus paper and press the pieces into the ash.

**Questions**

**6.2** What is the name of the substance formed when magnesium burns in air?

**6.3** Does this substance give an alkaline or an acidic reaction with litmus?

- Do the next part of the experiment in a fume cupboard or near an open window.

- Clean the gas jar. Moisten pieces of red and blue litmus paper and stick them on the inside of the jar.
- Place a little sulphur in the deflagrating spoon and set it alight by holding it in the Bunsen flame.
- Place the spoon of burning sulphur inside the jar. When it is extinguished, take it out and seal the jar with a cover slip.

**Questions**

**6.4** Describe the burning of sulphur. Did the sulphur melt? What was the colour of the flame? Was there any odour? What is the name of the gas that formed?

**6.5** Does the gas have an alkaline or an acidic reaction with moist litmus paper?

**EXPERIMENT 6.3**

*What effect does copper oxide have on moist litmus paper?*

**Each group will need:**

- piece of copper sheet
- tongs
- Bunsen burner
- red and blue litmus paper

**What to do**

- Heat the piece of copper in the Bunsen flame. You will find that the copper burns very slowly to form a thin black scale of copper oxide. Shake some of this on to a piece of paper.
- Press pieces of moist red and blue litmus paper on to the oxide. Make sure your fingers are clean when you do this.

**Question**

**6.6** Describe what happened when you pressed the litmus paper on to the oxide.

## Metals and non-metals

1. Metals
   - have shiny surfaces
   - are generally denser than non-metals
   - are malleable
   - are good conductors of heat and electricity.
2. Metals
   - can form compounds with non-metals
   - can be melted and mixed with other metals to form alloys.
3. Non-metals
   - can form compounds with metals
   - can form compounds with other non-metals.
4. If metallic oxides dissolve in water they form alkalis.
5. If non-metallic oxides dissolve in water they form acids.

## Spelling list

alkali
alkaline
alloy
exothermic
indicator
litmus
lustre
malleable
phosphorus
shiny
sulphur
synthesize

## Things to do

**6.7** Burn some (a) steel wool and (b) calcium in air, and test the oxides with litmus paper.

**6.8** Heat some carbon (charcoal) in a deflagrating spoon until it glows. Place the glowing carbon in a jar of oxygen. Test the carbon dioxide formed with moist litmus paper.

**6.9** Make your own "litmus" by crushing deeply coloured flower petals in a little water. Test the colour changes in vinegar and a solution of bicarbonate of soda.

**6.10** Using a pestle, grind a little mercury with iodine crystals in a mortar. A drop of water helps the reaction to start.

## More questions

**6.11** Name twenty metals and ten non-metals. (R)

**6.12** Name the compounds formed by combining (a) copper and sulphur, (b) zinc and chlorine, (c) calcium and phosphorus, (d) sodium and nitrogen, (e) potassium and iodine.

**6.13** Name three alloys not mentioned in this chapter. (R)

**6.14** What is amalgam? How is it made? (R)

**6.15** Name acids used in (a) first-aid kits, (b) motor cars, (c) soft drinks, (d) the kitchen. (R)

**6.16** State three ways of preventing iron from oxidizing in air.

## Test yourself (chapter 6)

Answer questions 1 to 5 by one word or a pair of words chosen from the list on the right. Write your answers in your workbook.

1. Name a non-metallic element.
2. Name an oxide that forms an alkali with water.
3. Name an oxide that forms an acid with water.
4. Name an alloy.
5. Name an oxide that does not dissolve in water.

iron oxide
copper
calcium oxide
carbon
brass
lead
copper oxide
mercury
tin
sulphur dioxide

In answering questions 6 to 12, choose the best answer and write its letter in your workbook.

6. Elements are usually divided into
   (a) acids and alkalis
   (b) metals and non-metals
   (c) compounds and mixtures
   (d) alloys and ores.
7. Which one of the following is a non-metallic element?
   (a) mercury
   (b) phosphorus
   (c) water
   (d) carbon dioxide.
8. Which of the following compounds can be produced by the combination of two non-metals?
   (a) iron chloride
   (b) magnesium oxide
   (c) copper sulphide
   (d) carbon dioxide.
9. When two elements combine they always produce
   (a) an oxide
   (b) a compound
   (c) a mixture
   (d) an alloy.
10. The formation of calcium oxide from its elements is a reaction between
    (a) two metals
    (b) two non-metals
    (c) a metal and a non-metal
    (d) an alkali and an acid.
11. A student carried out tests on four elements A, B, C and D. The results are shown in the table below. From these results, which of the four elements could he say is a metal?

| Element | Solid at room temperature? | Conducts electricity? | Can be hammered into sheets? |
|---|---|---|---|
| A | Yes | Yes | No |
| B | No | No | No |
| C | Yes | Yes | Yes |
| D | Yes | No | No |

# 7

# Acids, bases and salts

## Acids

Many acids may be found in the home. Among these are: boracic acid, used in ointment; carbonic acid, present in fizzy drinks; and citric acid, in lemons and oranges. There are, however, other acids, which although not found in the home are very much more important. Three of these are hydrochloric acid, nitric acid and sulphuric acid. Millions of tonnes of each are manufactured every year. In fact, a nation's industrial strength can be measured by the amount of sulphuric acid it produces.

## Mineral acids

The three acids hydrochloric, nitric and sulphuric are called mineral acids, because they were first produced from minerals. (See table 7.1.)

## Dilute acids

Acids are often used mixed with water. They are then said to be dilute. Care must be taken when diluting acids; *the acid must always be added to the water*. This is particularly important in the case of sulphuric acid. A lot of heat is generated when this acid is diluted. If only a little water were present, as it would be if you were adding water to acid, it would boil violently and spit some of the acid out of the vessel.

**Table 7.1:** Three important acids

| Acid | Old name | Formula | First made by |
|---|---|---|---|
| sulphuric acid | oil of vitriol | $H_2SO_4$ | heating green vitriol, $FeSO_4.7H_2O$ |
| hydrochloric acid | spirits of salt | $HCl$ | heating sulphuric acid and common salt, $NaCl$ |
| nitric acid | spirits of nitre | $HNO_3$ | heating sulphuric acid and nitre, $KNO_3$ |

Dilute acids are sour. Vinegar, lemon juice, the contents of the stomach and sour milk all contain acids. Dilute acids turn blue litmus red.

## Reaction with metals

Dilute acids attack many metals. A piece of clean magnesium ribbon, for example, is attacked by lemon juice. Bubbles of gas are given off and the metal slowly dissolves.

A more vigorous reaction takes place

when magnesium is added to dilute sulphuric acid. This reaction gives off enough gas to be tested. If a flame is applied, the gas will explode where it mixes with the air. The gas is hydrogen. Because the acid is a compound whereas the metal is an element, the hydrogen must come from it and not from the metal. The following equation explains what happens.

$$\text{magnesium} + \begin{array}{c}\text{dilute}\\ \text{sulphuric}\\ \text{acid}\end{array} \rightarrow \text{hydrogen} + \begin{array}{c}\text{magnesium}\\ \text{sulphate}\end{array}$$

$$Mg + H_2SO_4 \rightarrow H_2 + MgSO_4$$

If the liquid left in the test tube is evaporated as shown in figure 7.1, crystals of magnesium sulphate may be obtained.

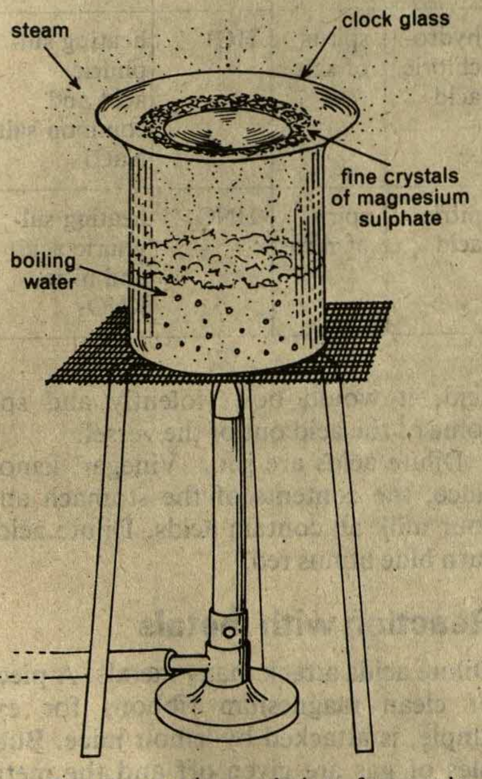


**Figure 7.1:** Evaporating a solution of magnesium sulphate to dryness. A deposit of very small crystals is left in the clock glass.

Magnesium sulphate is a salt. Salts are the compounds formed when the hydrogen in an acid is replaced by a metal. Because there are seventy different metals and hundreds of different acids, it is possible to produce thousands of different salts. Table 7.2 lists the groups of salts produced by some acids.

**Table 7.2:** Salts

| Acid | Group of salts produced |
|---|---|
| sulphuric acid | sulphates |
| nitric acid | nitrates |
| hydrochloric acid | chlorides |
| hydrofluoric acid | fluorides |
| carbonic acid | carbonates |
| citric acid | citrates |
| phosphoric acid | phosphates |
| acetic acid | acetates |

## Reaction with non-metals

When dilute hydrochloric acid is added to the non-metals carbon, phosphorus and sulphur, no apparent reaction occurs. The same result would be obtained with any dilute acid and any non-metal. From this we can conclude that dilute acids do not react with non-metals.

## Reaction with alkalis

Dilute acids turn blue litmus paper red; solutions of alkalis turn red litmus paper blue.

When dilute hydrochloric acid is added drop by drop to a caustic soda solution (alkaline), as shown in figure 7.2, the piece of litmus in the clock glass will eventually turn red. When this happens, we say that the acid has neutralized the alkali.

The following equation explains the chemical action that takes place.

sodium hydroxide + hydrochloric acid → sodium chloride + water

$$\mathrm{Na\,OH} + \mathrm{H\,Cl} \rightarrow \mathrm{Na\,Cl} + \mathrm{H_2O}$$

The liquid remaining in the clock glass is a solution of sodium chloride. Sodium chloride is a salt and may be recovered by evaporation, as shown in figure 7.1.

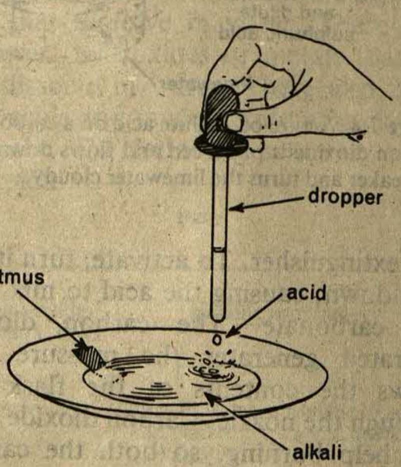


**Figure 7.2:** Neutralizing caustic soda solution with hydrochloric acid. At the point of neutralization the litmus paper begins to change from blue to red.

Any acid can be used to neutralize any alkali; in all cases a salt and water form.

**alkali + acid → salt + water**

## Reaction with metallic oxides

Dilute acids react with most metallic oxides. An example is the action of dilute sulphuric acid with copper oxide. About 3 cm of the acid is heated in a 2 cm test tube until it is almost boiling. Copper oxide is then added, a little at a time, until some remains undissolved. The liquid should be stirred to assist the reaction. (See figure 7.3.)

The contents of the test tube are filtered through a funnel into a clock glass. Providing the sulphuric acid used in the experiment was not too dilute, copper sulphate crystals should form as the solution cools. The following equation explains the chemical reaction.

copper oxide + dilute sulphuric acid → copper sulphate + water

$$\mathrm{Cu\,O} + \mathrm{H_2\,SO_4} \rightarrow \mathrm{CuSO_4} + \mathrm{H_2O}$$

**metallic oxide + acid → salt + water**

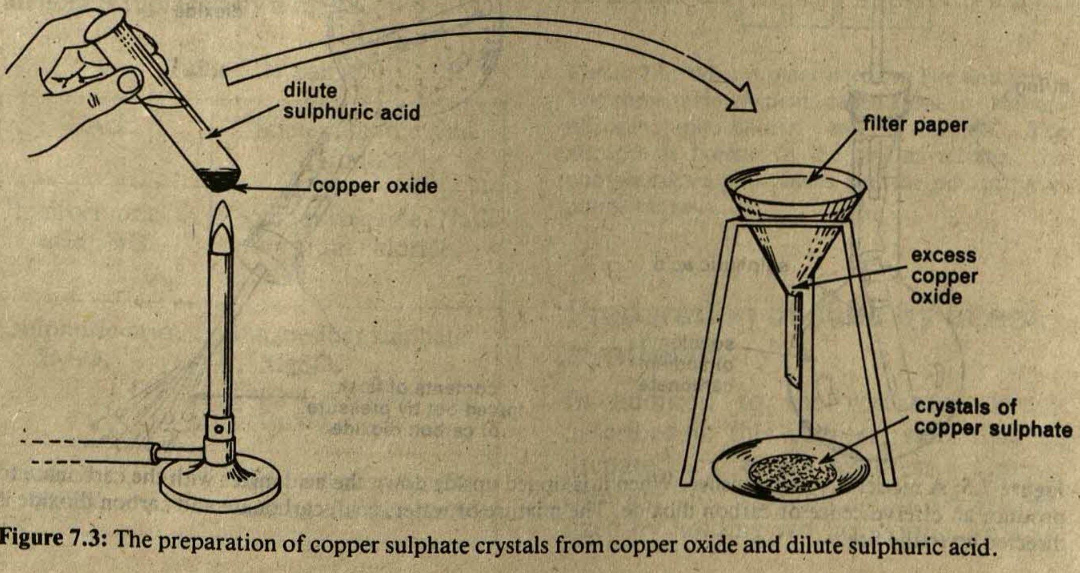


**Figure 7.3:** The preparation of copper sulphate crystals from copper oxide and dilute sulphuric acid.

## Reaction with carbonates

A refreshing effervescent drink may be made by adding a pinch of carbonate of soda to ice cold lemon juice and water. The citric acid in the lemon reacts with the carbonate to form bubbles of carbon dioxide.

Another example of the same kind of action is shown in figure 7.4. Here the gas given off is allowed to pour down into a beaker containing some limewater. A white precipitate forms in the limewater, thus verifying that the gas is carbon dioxide.

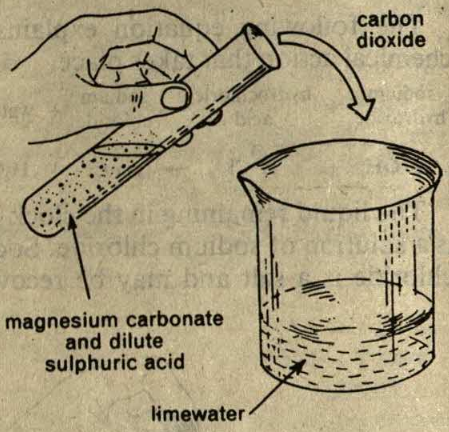


**Figure 7.4:** Action of a dilute acid on a carbonate. Carbon dioxide is produced and flows down into the beaker and turns the limewater cloudy.

The formation of the carbon dioxide is explained by the following equation.

magnesium carbonate + dilute sulphuric acid → magnesium sulphate + carbon dioxide + water

$$MgCO_3 + H_2SO_4 \rightarrow MgSO_4 + CO_2 + H_2O$$

Whenever an acid acts on a carbonate, carbon dioxide, a salt and water are formed.

**carbonate + acid → salt + carbon dioxide + water**

Figure 7.5 shows how to make a model fire extinguisher. To activate, turn it upside down, causing the acid to mix with the carbonate. The carbon dioxide liberated generates the pressure that blows the contents of the flask out through the nozzle. Carbon dioxide does not help burning, so both the carbon dioxide and the water put out the fire.

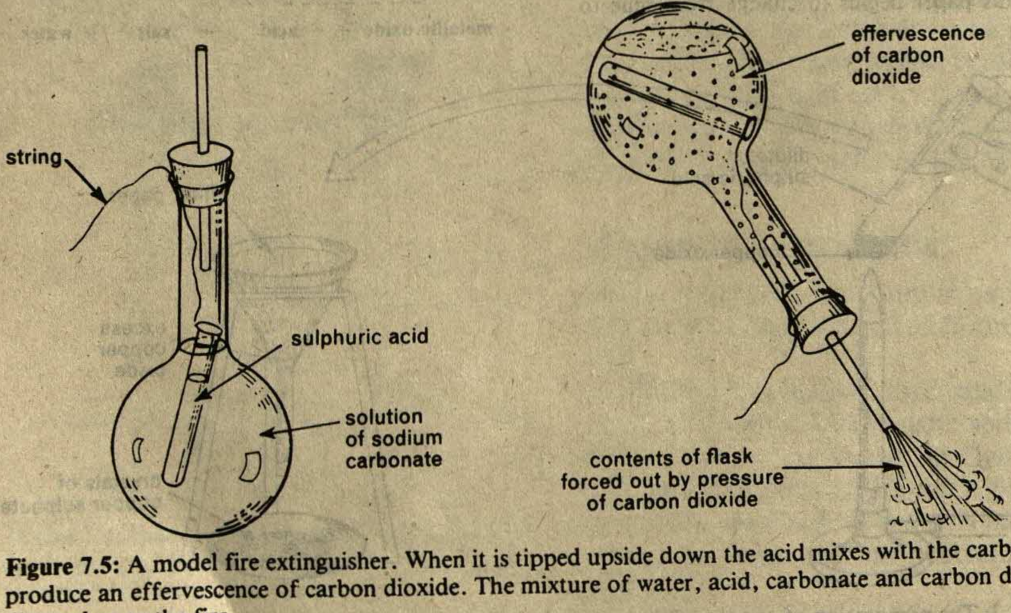

string
sulphuric acid
solution of sodium carbonate
effervescence of carbon dioxide
contents of flask forced out by pressure of carbon dioxide

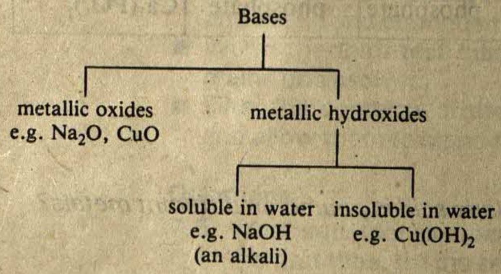
**Figure 7.5:** A model fire extinguisher. When it is tipped upside down the acid mixes with the carbonate to produce an effervescence of carbon dioxide. The mixture of water, acid, carbonate and carbon dioxide is directed on to the fire.

## Bases

We have just seen that both metallic oxides and alkalis react with acids to produce a salt and water only. Compounds that react with acids in this way are called bases. Thus

**base + acid ⟶ salt + water**

Alkalis are not the only hydroxides that react with acids. Alkalis are hydroxides that dissolve in water. There are, however, hydroxides of metals that do not dissolve in water. These also react with acids and must therefore be classed as bases. The following summary helps to explain.



## Salts

Salts are formed when the hydrogen of an acid is replaced by a metal.

**Table 7.2:** Salts

| Acid | Some salts the acid produces |
|---|---|
| hydrochloric acid, HCl | sodium chloride, NaCl<br>potassium chloride, KCl |
| sulphuric acid, $H_2SO_4$ | magnesium sulphate, $MgSO_4$<br>copper sulphate, $CuSO_4$ |
| nitric acid, $HNO_3$ | silver nitrate, $AgNO_3$<br>sodium nitrate, $NaNO_3$ |

Salts occur in rocks, in the soil and in the sea. Large deposits of salt in the earth's crust are often the result of the drying up of ancient inland seas. Common salt and potassium chloride occur in this way. It has been estimated, for example, that if the Dead Sea dries up it will leave 12 000 000 tonnes of salts.

Plants require certain elements for growth. Figure 7.6 lists these elements. They occur in salts in the soil, mainly as carbonates, phosphates, nitrates, sulphates, chloride and borates.

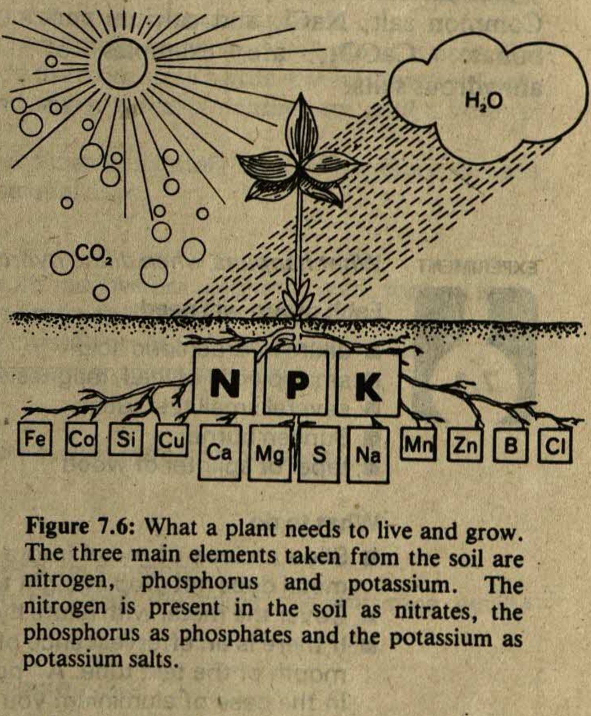


**Figure 7.6:** What a plant needs to live and grow. The three main elements taken from the soil are nitrogen, phosphorus and potassium. The nitrogen is present in the soil as nitrates, the phosphorus as phosphates and the potassium as potassium salts.

## Preparation of salts by direct synthesis

In addition to the methods already described in this chapter, salts may be prepared by direct synthesis. Copper chloride, for example, may be synthesized by holding red hot copper in a jar of chlorine. The copper burns in the chlorine, forming a brown deposit of copper chloride. This turns green when dissolved in water.

## Hydrated salts

Many salts occur combined with water. Epsom salt, $MgSO_4.7H_2O$, and bluestone, $CuSO_4.5H_2O$, are examples. The water is called water of crystallization. It may be separated from the salt by heating.

Not all salts are hydrated, however. Common salt, NaCl, and calcium carbonate, $CaCO_3$, are examples of anhydrous salts.

**Table 7.3:** Salts in common use

| Common name | Chemical name | Formula |
|---|---|---|
| common salt | sodium chloride | NaCl |
| Epsom salt | magnesium sulphate | $MgSO_4.7H_2O$ |
| saltpetre | potassium nitrate | $KNO_3$ |
| marble | calcium carbonate | $CaCO_3$ |
| gypsum | calcium sulphate | $CaSO_4.2H_2O$ |
| bicarbonate of soda | sodium bicarbonate | $NaHCO_3$ |
| rock phosphate | calcium phosphate | $Ca_3(PO_4)_2$ |

**EXPERIMENT**

**7.1**

*What happens when dilute hydrochloric acid is poured on different metals?*

**Each group will need:**

- dilute hydrochloric acid
- small pieces of lead, magnesium, calcium, iron, aluminium and copper
- several small test tubes
- Bunsen burner
- taper or splinter of wood

**What to do**

- Slide a piece of metal into a test tube. Incline the test tube so that the metal does not drop straight to the bottom and crack it.
- Cover the metal with dilute hydrochloric acid.
- If there is an effervescence of gas, test it by placing a burning taper at the mouth of the test tube. A "pop" is evidence of the presence of hydrogen. In the case of aluminium you may have to wait for several minutes for an action to begin, because the acid has to penetrate a layer of oxide.
- Repeat for each metal.
- Tabulate your results.

**Questions**

**7.1** Which metals reacted with the acid almost immediately?
**7.2** Which metals reacted after a delay?
**7.3** Can you suggest a reason for the delay?
**7.4** Which metals did not react at all?

**EXPERIMENT**

**7.2**

### *Preparing magnesium sulphate by three different methods*

**Each group will need:**

- enough magnesium carbonate to cover a cent piece
- a similar amount of magnesium oxide (Magnesium oxide may be prepared beforehand by heating dry magnesium carbonate in an evaporating basin.)
- three 2 cm test tubes
- five centimetres of magnesium ribbon broken into half-centimetre pieces
- filter funnel and stand
- three filter papers
- three clock glasses

**What to do**

- Take three test tubes, each 2 cm in diameter.
- Add about 1 cm of dilute sulphuric acid to each.
- Add pieces of magnesium to the first test tube until the effervescence ceases and a little of the magnesium remains undissolved.
- Warm the second test tube. Add magnesium oxide a little at a time. Stir and shake and continue to add the oxide until a little remains undissolved.
- Warm the third test tube and add magnesium carbonate until a little remains undissolved.
- Filter the contents of the test tubes separately on to three clock glasses and allow them to stand for several days.

**Questions**

7.5 What substances, apart from magnesium sulphate, were formed in (a) the first tube, (b) the second tube and (c) the third tube?

7.6 Describe the shapes of the crystals on each clock glass.

7.7 What is the common name for magnesium sulphate?

**EXPERIMENT**

**7.3**

### *Neutralizing caustic soda solution by two different methods*

**Each group will need:**

- two 100 mL beakers
- two 25 mL lots of sodium hydroxide solution
- a bottle of hydrochloric acid of about the same concentration as the sodium hydroxide solution
- red litmus paper
- dropper with rubber top (See figure 7.2.)
- thermometer
- glass stirrer

**What to do**

- Add the litmus paper to one lot of alkali (lot A).
- Mark the dropper with a felt pen so that it delivers about 1 mL in each delivery of liquid.
- Neutralize the alkali, using the dropper to estimate the quantity of acid needed to turn the litmus red. Stir the solution after each dropper-full is added. Count the number needed.

- Take the temperature of the second lot of alkali (lot B).
- Add one dropper-full of acid to the alkali, stir, then take the temperature again.
- Repeat this until the temperature begins to fall after the addition of more acid.
- Copy and complete the following tables.

| | |
|---|---|
| Number of droppers-full of acid needed to neutralize lot A | |

| Number of droppers-full of acid added to lot B | Temperature of mixture (°C) |
|---|---|
| 0 | |
| 1 | |
| 2 | |
| 3 | |

**Question**

**7.8** How many droppers-full of acid were needed to complete the neutralization of the second lot of alkali?

## Acids

- Acids are compounds containing hydrogen.
- The hydrogen may be replaced by a metal to form a salt.
- When dissolved in water, acids have a sour taste and turn blue litmus red.
- Acids neutralize bases to form a salt and water.
- Acids liberate carbon dioxide from carbonates.

## Bases

- Oxides and hydroxides of metals are bases.
- If soluble in water, bases turn red litmus blue.
- Bases neutralize acids to form a salt and water.

## Salts

- Salts are compounds formed when the hydrogen of an acid is replaced by a metal.
- Salts may be prepared by direct synthesis or by the action of acids on metals, bases or carbonates.

## Spelling list

alkali
anhydrous
effervescence
evaporate
exothermic
extinguish
funnel
hydrated
hydrochloric
metallic
mineral
neutralize
nitric
sulphuric
synthesis

## Things to do

7.9 Try the effect of mineral acids on various plastics, including fabrics made from polymers such as polyesters.

7.10 Oil of wintergreen is used extensively in liniments used for rubbing. Make some by warming a mixture of methanol and salicylic acid to which a few drops of concentrated sulphuric acid have been added. Do you recognize the odour of the substance you have prepared?

7.11 Prepare some zinc sulphate crystals by adding dilute sulphuric acid to zinc. Use a clock glass for crystallization.

7.12 Prepare sodium sulphate crystals by adding dilute sulphuric acid to sodium carbonate.

## More questions

7.13 Give six facts that apply to most acids.

7.14 Name two liquid acids and two crystalline acids. (R)

7.15 Give three facts that apply to bases.

7.16 What is an alkali? Name two alkalis.

7.17 What is a salt? Name twenty salts.

7.18 Salts are found in inland seas, and oceans. Where do they come from?

7.19 Can you suggest a reason for the high salinity of the Dead Sea? The Red Sea is more salty than the Baltic Sea. Why?

7.20 How would you prepare a sample of zinc chloride starting from (a) zinc, (b) zinc oxide, (c) zinc carbonate?

7.21 The elements required in greatest amounts by plants are carbon, hydrogen, oxygen, nitrogen, potassium and phosphorus. Name compounds that can supply these elements to plants. (R)

7.22 A bottle of spirits of salt is dropped and broken on the kitchen floor. How would you remove the acid?

7.23 Milk of magnesia is a mixture of magnesium oxide and magnesium hydroxide in water. Why is it better than carbonate of soda for treating excess acid in the stomach?

## Test yourself (chapter 7)

Write the answers to questions 1 to 4 in your workbook.

1. A colourless liquid turns blue litmus paper red and reacts with

magnesium to produce a gas. What type of substance must the colourless liquid be?

2. Name three mineral acids.
3. Name two chemicals that will react together to form nickel nitrate.
4. The following table deals with the neutralization of alkalis by acids to form salts. Copy and complete it.

| Alkali | Salt formed with | | |
|---|---|---|---|
| | hydrochloric acid | nitric acid | sulphuric acid |
| sodium hydroxide | (a) | (d) | (g) |
| potassium hydroxide | (b) | (e) | (h) |
| calcium hydroxide | (c) | (f) | (i) |

In questions 5 to 7, choose the best answer and write its letter in your workbook.

5. In which of the following cases will a gas be given off?
   (a) Hydrochloric acid is added to sodium carbonate.
   (b) Sulphuric acid is added to sodium hydroxide.
   (c) Sulphuric acid is added to copper oxide.
   (d) Hydrochloric acid is added to copper.
6. Which of the following can be used to neutralize an acid?
   (a) common salt
   (b) calcium hydroxide
   (c) vinegar
   (d) water.
7. Three colourless liquids, P, Q and R, are tested with red and blue litmus paper with the following results:

| | P | Q | R |
|---|---|---|---|
| Add red litmus | stays red | stays red | turns blue |
| Add blue litmus | turns red | stays blue | stays blue |

Using the above information, which of the following is correct for all three liquids?

| | P | Q | R |
|---|---|---|---|
| (a) | is an acid | is neither an acid nor an alkali | is an alkali |
| (b) | is an alkali | is neither an acid nor an alkali | is an acid |
| (c) | is an acid | is an acid | is an alkali |
| (d) | is an acid | is an alkali | is an alkali |

# 8

# Atoms

## Early ideas

What materials are really made of is a question that has intrigued people for thousands of years. The early Greeks were among the first to propose that the many different substances on the earth were made from a few simpler substances called elements. They could not decide, however, whether these simpler substances were themselves made up of minute particles (which they called atoms) or whether the substances were continuous.

The atomic theory stated that substances could be divided into smaller and smaller pieces until the pieces were so small that they could not be divided any further. These pieces were the atoms.

The continuous theory stated that there was no limit to the amount of dividing that could be done; it could go on and on without end. There were no such things as atoms.

## Need for an atomic theory

During the eighteenth century, scientists began to understand that certain substances — such as gold, tin and carbon — were elements, and that many other substances — such as acids and salts — were compounds made from elements.

In their efforts to explain how compounds were formed from elements, the scientists found that an atomic theory was more useful than a continuous theory. It was known, for example, that whenever copper burnt to form copper oxide, four grams of copper combined with one gram of oxygen to produce five grams of copper oxide. The easiest way of explaining this is to say that copper oxide is made up of copper atoms joined to oxygen atoms, and that each copper atom is four times as heavy as each oxygen atom.

## Dalton's atomic theory

John Dalton, an Englishman, proposed an atomic theory in 1808 in which he imagined atoms to be tiny solid balls. He said:

- All matter is made up of atoms.
- Each element has its own kind of atom. For example, all atoms of silver are the same but are different from atoms of gold.
- Compounds are formed when atoms of different elements join together. Water, for example, is formed by the joining of atoms of hydrogen and oxygen.

## Comparing weights of atoms

We have just explained how it was first calculated that the copper atom is four times as heavy as the oxygen atom. By preparing many different compounds and finding out the weights of the different elements in them, Dalton was able to make a list of different atoms in the order of their weights. Hydrogen was found to have the lightest atom and lead one of the heaviest. Table 8.1 compares the weights of the atoms of some elements and shows how many times each atom is heavier than the hydrogen atom.

**Table 8.1:** Comparing atomic weights

| Element | Symbol | Weight of its atom compared with the hydrogen atom |
|---|---|---|
| Hydrogen | H | 1 |
| Carbon | C | 12 |
| Oxygen | O | 16 |
| Copper | Cu | 64 |
| Mercury | Hg | 201 |
| Lead | Pb | 207 |

Dalton pictured atoms as small hard balls. Today we still use this idea to explain how atoms are joined together in compounds. Figure 8.1 shows which atoms are joined together in the compounds water and carbon dioxide.

In the years after 1808, investigations were taking place in the field of electricity. These investigations showed that atoms were not the small hard balls Dalton imagined them to be.

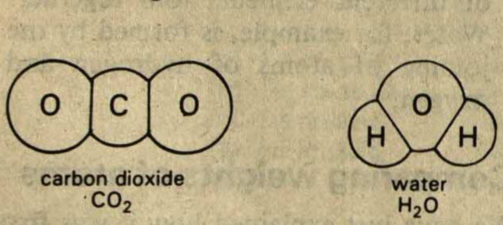


**Figure 8.1:** Using models to explain what atoms are present in carbon dioxide and water.

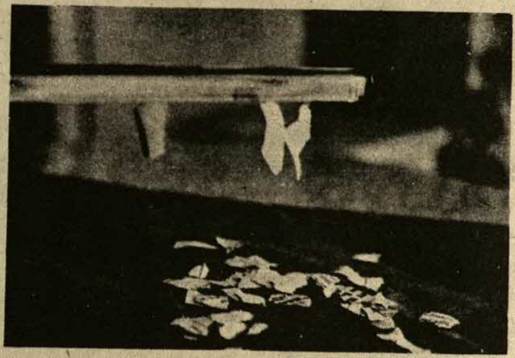


**Figure 8.2:** A charged rod picking up pieces of paper.

## What is electricity?

Have you ever heard crackling sounds when removing a garment such as a polyester shirt or blouse? As well, you will no doubt have picked up small pieces of paper with a plastic-cased pen that you have rubbed on your sleeve. These things happen because the shirt and the plastic-cased pen have become electrified.

The early Greeks noticed these sorts of effects, which are produced by rubbing things. They said the objects became covered with a substance that they called electricity. The word electricity is derived from *elektron*, the Greek word for amber. Amber is a natural gum that the Greeks found could be very readily charged (electrified) by rubbing.

The production of electric charges by rubbing substances is investigated more fully in experiment 8.1.

## Two kinds of electricity

The Greek theory, explaining electriciy as a substance, is not very different from the theory of electricity we use today. However, we have taken it a step further. We say there are two kinds of electricity; we call these two kinds positive and negative. It is hard to understand why the words "positive" and "negative" were chosen to describe the two kinds, except that names were needed that gave the idea of opposites.

Figures 8.3 and 8.4 show an experiment that demonstrates the existence of these two kinds of electricity. The ends of two perspex rods are electrified in exactly the same way, by rubbing them with silk. We therefore assume both rods become charged with the same kind of electricity. One rod is balanced carefully on an upturned clock glass and the other brought near it, as in figure 8.5. The rod on the clock glass moves away, as though it was pushed away by the first rod. We say that two lots, or charges, of electricity of the same kind repel each other.

*Like charges repel.*

If we now repeat the experiment but use an ebonite rod and a perspex rod instead of two perspex rods, we find the rods attract one another. Obviously something different has happened. We say that the ebonite rod has become charged with a different kind of electricity.

*Unlike charges attract.*

## Electricity explained

The existence of two kinds of electricity can be explained as follows.

All objects are normally electrically neutral. This is because they have equal quantities of positive and negative electricity. Rubbing an object may remove some of the positive electricity or it may remove some of the negative electricity. If some of the positive electricity is removed, a surplus of negative electricity remains and the object becomes negatively charged. In the same way, removal of some negative electricity leaves an object positively charged.

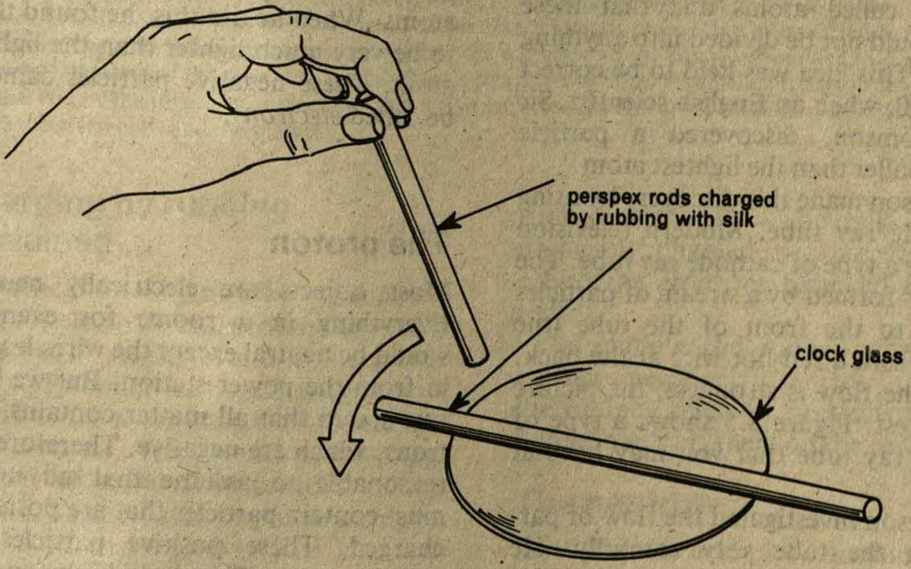


**Figure 8.3:** Like charges repel. Two similarly charged rods repelling one another.

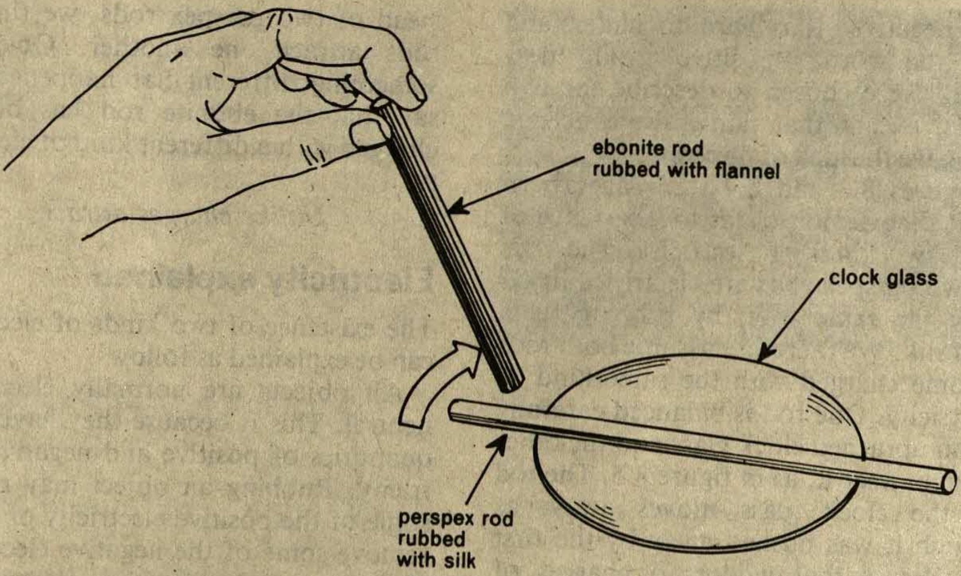


**Figure 8.4:** Unlike charges attract. A charged ebonite rod attracting a charged perspex rod.

## The electron

At the beginning of this chapter we said that all substances were made up of tiny particles called atoms and that these atoms could not be divided into anything smaller. This idea was held to be correct until 1900, when an English scientist, Sir J. J. Thomson, discovered a particle much smaller than the lightest atom.

Thomson made this discovery by using a cathode ray tube. Modern television tubes are a type of cathode ray tube. The picture is formed by a stream of particles flowing to the front of the tube (the screen) from a red-hot wire at the back. Where the flow is strongest, the picture is brightest. Figure 8.5 shows a type of cathode ray tube that you may have at school.

Thomson investigated the flow of particles in the tube very carefully. He found they were attracted to a positive charge. Therefore, they must be negatively charged. He also found that these particles were present in every substance tested. He was able to compare their weight with the weights of atoms. When he did this, he found them to be very much lighter than the lightest atom. These negative particles came to be called *electrons.*

## The proton

Most objects are electrically neutral. Everything in a room, for example, would be neutral except the wires leading in from the power station. But we have just stated that all matter contains electrons, which are negative. Therefore it is reasonable to assume that all matter must contain particles that are positively charged. These positive particles are called protons. They have been found to be much heavier than electrons.

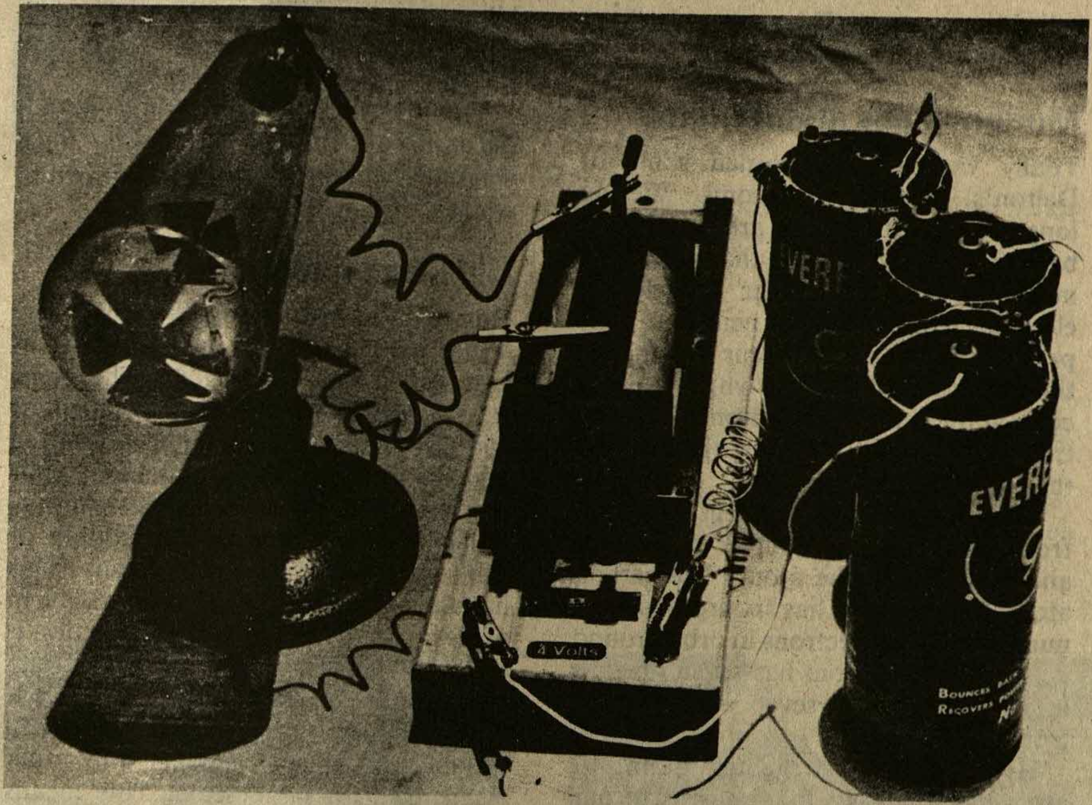


**Figure 8.5:** Using a Maltese-cross tube to investigate the flow of electrons. The tube has no gas in it. At the far end is a circular piece of metal that is connected to the negative terminal of a high voltage coil. In the middle of the tube is another piece of metal, shaped like a Maltese cross. This is connected to the positive terminal of the coil. When the current is switched on, a shadow of the cross, surrounded by a green glow, appears on this end of the tube. The whole effect is produced by electrons flowing from the negative to the positive end of the tube. Those electrons that strike the cross are absorbed; those that miss it pass on and create the green glow and the shadow.

## Charging by rubbing explained

Electrification may now be explained in terms of electrons and protons instead of in terms of negative and positive electricity. Rubbing an object may remove electrons from the atoms on the surface of the object. This would leave a large number of unbalanced protons on this surface, thus creating a positive charge. The cloth that removed the electrons would become negatively charged.

This is what happens when perspex is rubbed with silk. The silk becomes negatively charged because it has received the electrons removed from the rod.

An ebonite rod rubbed with flannel becomes negatively charged. In this case the rubbing removes electrons from the flannel and puts them on the rod.

## The neutron

In 1932 a third kind of atomic particle was discovered. It was found to be electrically neutral and for this reason was called the neutron. The neutron is about the same weight as the proton.

## Modern ideas about atoms

Today we have abandoned some of Dalton's ideas about atoms. We no longer believe that they are small solid balls. Instead we believe that atoms are made up of even smaller particles — electrons, protons and neutrons. The protons and neutrons occur together in the *nucleus* of the atom, which is like a core, at the centre of the atom. The electrons move in orbits around the nucleus; they move very rapidly.

What makes one element different from another is the number of protons and electrons in the atom. The carbon atom, for example, has six protons in its nucleus with six electrons in orbit around it; the nitrogen atom has seven protons in its nucleus with seven orbiting electrons.

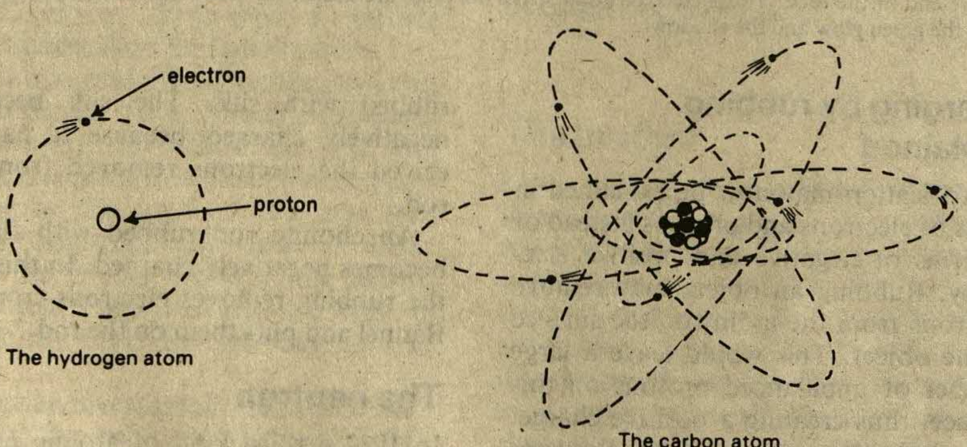
Hydrogen has the lightest atom. Its atom has a nucleus that consists of one proton, with one electron in orbit around it. If we imagine this proton to be the size of an orange, the orbiting electron needs to be placed eight kilometres away to keep the same scale. Atoms, far from being solid, are therefore mostly empty space.

The diagrams in figure 8.6 represent the atoms of hydrogen and carbon. Such diagrams cannot, of course, be drawn to scale.

## Old ideas renewed

Hundreds of years ago alchemists were trying to change base metals (such as lead and copper) into gold. The quest was eventually thought to be ridiculous and was abandoned. Today it is realized that the idea was not so ridiculous after all. We now know that one element may be changed into another by adding or subtracting protons and electrons. This has already been done on a small scale in nuclear reactors. (This sort of reaction is called a nuclear reaction, as distinct from a chemical reaction.)

It is possible that in the future we will be able to change elements into other elements on a large scale. This means that we will then have the power to change less valuable elements into useful elements that are in short supply on the earth.



The hydrogen atom

The carbon atom

**Figure 8.6:** These two diagrams show models of the hydrogen atom and the carbon atom. The carbon atom has six protons, six neutrons and six electrons.

**EXPERIMENT**

**8.1**

## *Tricks with electricity*

*Note:* These experiments do not work satisfactorily during damp or humid weather.

### Each group will need:

- squares (about 20 cm × 20 cm) of wool, cotton and synthetic cloth
- rulers (wooden, plastic and metal)
- strips (about 20 cm × 2 cm) of various plastic materials from such things as shirt boxes, ice cream containers, old refrigerator trays, etc.
- sawdust
- pieces of paper
- metal powder

### What to do

- Label the plastic strips A, B, C, etc., with a felt pen.
- Try to electrify the rulers and labelled plastic strips by rubbing them with one or another of the cloth squares.
- Test each ruler or strip to see whether it attracts pieces of paper, sawdust, metal powder, a stream of water (see figure 8.7) or the hairs on your partner's head (see figure 8.8).

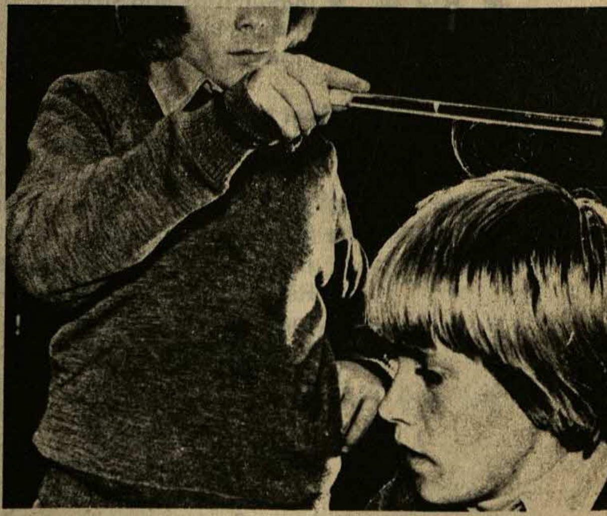


**Figure 8.8:** The hairs on the boy's head are attracted to the charged rod in the same way as the pieces of paper were picked up by the rod in figure 8.2.

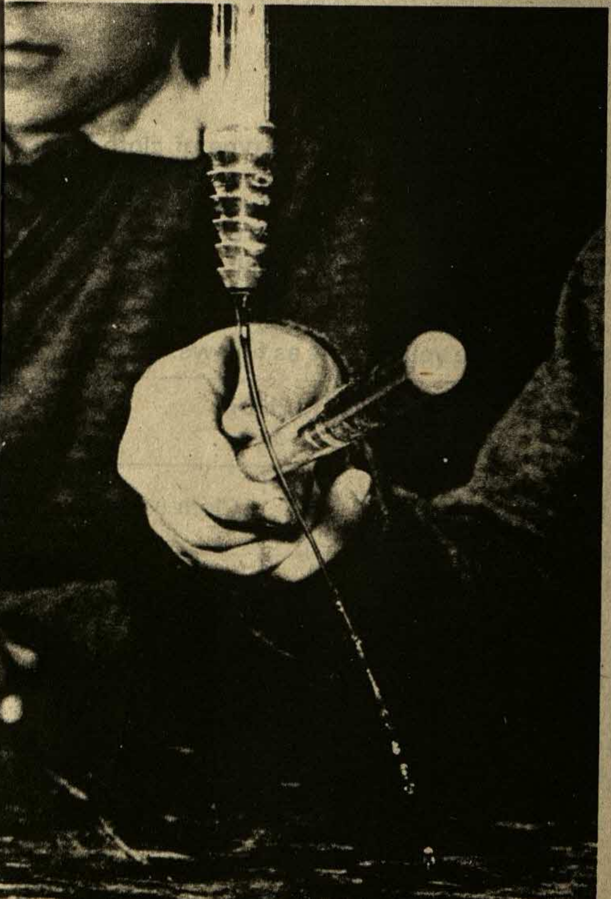


**Figure 8.7:** A stream of water is attracted to a plastic rod charged with electricity.

- Copy the following table and use it to record your results. Put two ticks for a good result, one tick for a fair result and a cross for no result.

| Rubbed ruler or strip | Effect on | | | | |
|---|---|---|---|---|---|
| | paper | sawdust | metal powder | stream of water | hairs |
| | | | | | |

**Questions**

**8.1** Which pair — strip or ruler and cloth — gave the best set of results?
**8.2** Did any ruler or strip give no result at all, with anything?

**EXPERIMENT 8.2**

*How can you tell whether electric charges are the same or different?*

**Each group will need:**

- squares of different fabrics
- plastic rods and strips
- various kinds of rulers
- clock glass

**What to do**

- Charge a plastic rod by rubbing it with a cloth. (Choose a type of cloth from experiment 8.1 that gave a good result.)
- Balance the rod on an upturned clock glass, as in figure 8.3.
- Now charge another rod by rubbing (with any of the pieces of cloth). Hold this rod near the charged rod on the clock glass. What happens? Remember that attraction means the two charges are opposite; repulsion means they are the same.
- Try each of the materials in turn and tabulate your results as follows.

| Same as charge on test rod | | Opposite to charge on test rod | |
|---|---|---|---|
| Material of ruler or strip | Cloth used | Material of ruler or strip | Cloth used |
| | | | |

**Question**

**8.3** Did any of the strips or rulers consistently give no effect? Which ones?

## Atoms

1. Atoms are extremely small — about 100 million placed side by side would fit in a centimetre.
2. Atoms have a positive nucleus.
3. Atoms have electrons orbiting around the nucleus.
4. Objects may be charged positively by electrons being rubbed off.
5. Objects may be charged negatively by electrons being added on.
6. Like charges repel and unlike charges attract.

## Spelling list

cathode ray tube
ebonite
electricity
electrons
neutral
nucleus
orbit
particle
perspex
polyester
repel
repulsion
synthetic

## Things to do

**8.4** Have you a Van de Graaff generator at your school? If you have, charge a person with short hair and notice how the hair stands up. Do this by having the person stand on some glass slabs and place his hands on the top of the generator.

**8.5** You can make an instrument called an electrophorus using a gramophone record and the flat metal lid of a biscuit tin. Fit an insulating handle to the lid. (A piece of stiff plastic stuck on with plasticine will do.)

Charge the metal lid in the following way:

(a) First charge the gramophone record by rubbing it with a piece of flannel.
(b) Place the lid on the record.
(c) Touch the lid with your finger.
(d) Lift the lid off by the insulated handle.

The lid is now charged with electricity. If you bring the lid near your ear, you will hear a spark as the charge jumps across to your body. You can light a Bunsen by bringing the charged lid close to the burner with the gas turned on lightly; you can also flash a small fluorescent tube by touching one end with the lid.

## More questions

**8.6** List the main points of Dalton's atomic theory.
**8.7** Name three different particles found in atoms.
**8.8** Name the lightest atom. What particles does it contain?
**8.9** Explain what happens when an object is charged positively by rubbing.
**8.10** Matter is mostly empty space. Explain what this means.
**8.11** State the law of attraction and repulsion of charges.
**8.12** Why do experiments on electricity work best on dry days?
**8.13** Motor car bodies sometimes become charged with electricity while moving along the road. How do you explain this?
**8.14** A nylon shirt sometimes clings to a person's body as it is pulled off. Explain this.
**8.15** The uranium atom has a nucleus containing 92 protons and 146 neutrons. Complete the picture of the atom. (R)

## Test yourself (chapter 8)

Write the answers to questions 1 to 3 in your workbook.

1. Name three particles present in atoms.
2. An object carries a negative charge. The object must therefore have a surplus of __________.
3. Complete the following statement: "Unlike charges __________."

Choose the best answer to questions 4 and 5 and write its letter in your workbook.

4. A perspex rod is rubbed with silk and balanced on a clock glass. A plastic ruler rubbed with cloth is found to repel the perspex rod. From this we can conclude that:
   (a) The charge on the perspex rod is opposite to the charge on the ruler.
   (b) The charge on the perspex rod is the same as the charge on the ruler.
   (c) The charge on the ruler is negative.
   (d) The charge on the ruler is positive.
5. A copper rod is held in one hand and rubbed with a flannel cloth held in the other. It is found that the rubbing does not charge the copper. The most satisfying explanation for the absence of charge is:
   (a) The rod was rubbed with the wrong type of cloth.
   (b) Copper always has an equal number of protons and electrons.
   (c) Any charge produced on the copper is conducted into the hand.
   (d) It is very difficult to charge copper.

# 9

# Electrolytes

In chapter 6 we tested a number of solids to see whether they conducted electricity. We found that metals are good conductors of electricity and non-metals are bad conductors.

In this chapter we shall test the electrical conductivity of a number of liquids. The first liquid to be tested will be distilled water.

## Testing water for conductivity

The apparatus used is shown in figure 9.1. When a piece of metal is placed across the gap between the two stainless steel plates, the circuit is complete and the bulb lights up. It does not light up when water is poured into the beaker. This shows that distilled water does not conduct electricity across the gap between the plates.

The water is now replaced by a solution of common salt. This time the bulb lights up. Evidently a solution of common salt is a conductor of electricity.

The same apparatus may be used to test the conductivity of other solutions and liquids. The results of some tests are shown in table 9.1.

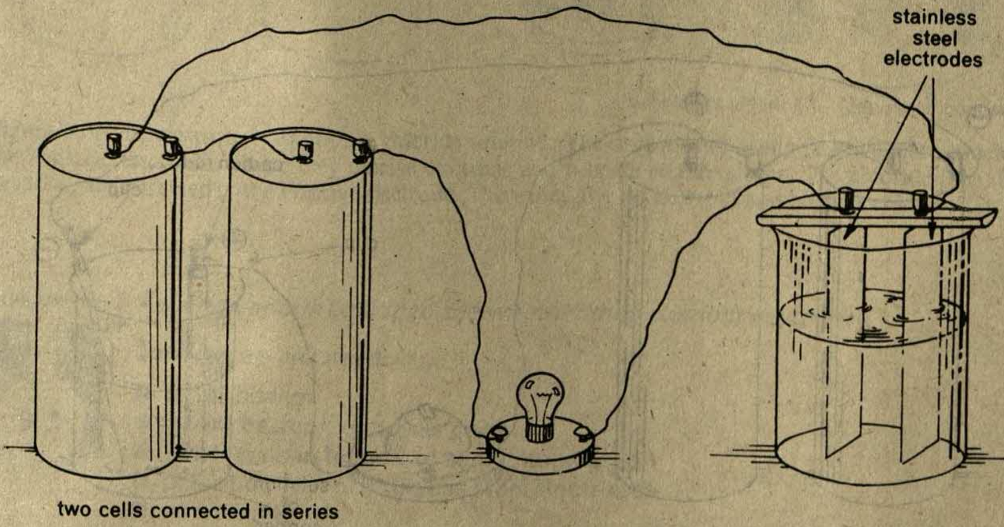


**Figure 9.1:** Testing a liquid to see whether it conducts electricity. When electricity flows through the liquid the bulb lights.

**Table 9.1:** Conductivity of liquids and solutions

| Conductors | Non-conductors |
|---|---|
| Solutions of:<br>hydrochloric acid<br>sulphuric acid<br>nitric acid<br>sodium chloride<br>copper sulphate<br>sodium carbonate<br>sodium hydroxide<br>potassium hydroxide | water<br>methylated spirits<br>kerosene<br>petrol<br>solution of cane sugar<br>solution of glucose |

These results show that solutions of acids, salts and alkalis conduct electricity whereas the other liquids and solutions do not. Acids, salts and alkalis are called electrolytes. Electrolytes are compounds that conduct electricity when dissolved in water.

## Electrolysis

A metal teaspoon may be electroplated with copper by using the apparatus shown in figure 9.2. The electrolyte must be a salt of copper. In this experiment copper chloride is used. The spoon is connected to the negative terminal of the battery. The spoon is therefore the negative electrode, or cathode. The carbon rod is connected to the positive terminal of the battery and is therefore the positive electrode, or anode.

After the current is passed through the solution for some minutes, the spoon becomes coated with copper on the side facing the carbon rod. (See figure 9.2.) Bubbles of gas come from the surface of the anode. The odour of this gas indicates that it is chlorine.

It should be noted that the copper appears on the cathode and the chlorine is given off at the anode. The reaction may be stated as follows:

copper chloride + electrical energy → copper + chlorine

This process is called electrolysis. Electrolysis is the decomposition of an electrolyte by electrical energy.

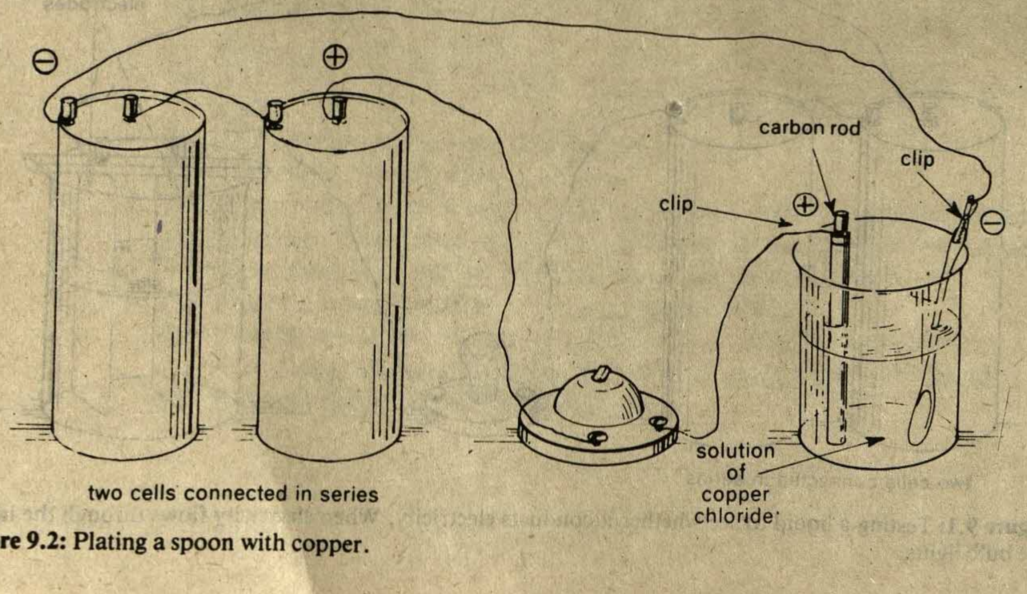


**Figure 9.2:** Plating a spoon with copper.

## Electrolysis explained

Look again at figure 9.2. Note that the spoon is connected to the negative terminal of the battery. Because copper is attracted to the spoon we assume the copper particles must be positively charged (since unlike charges are attracted to one another). By the same reasoning, the particles of chlorine must be negatively charged because they are attracted to the positive electrode. Charged particles in a solution such as this are called ions.

copper chloride → copper ions + chloride ions

$$CuCl_2 \rightarrow Cu^{2+} + Cl^- + Cl^-$$

Note that there are twice as many chloride ions as copper ions. Therefore, each copper ion must carry twice as much charge as each chloride ion.

Figure 9.3 illustrates the movement of the ions towards the electrodes. When the copper ions reach the cathode, the positive charge on each ion is neutralized and it becomes a copper atom. The chloride ions are neutralized at the anode, where they become atoms of chlorine gas.

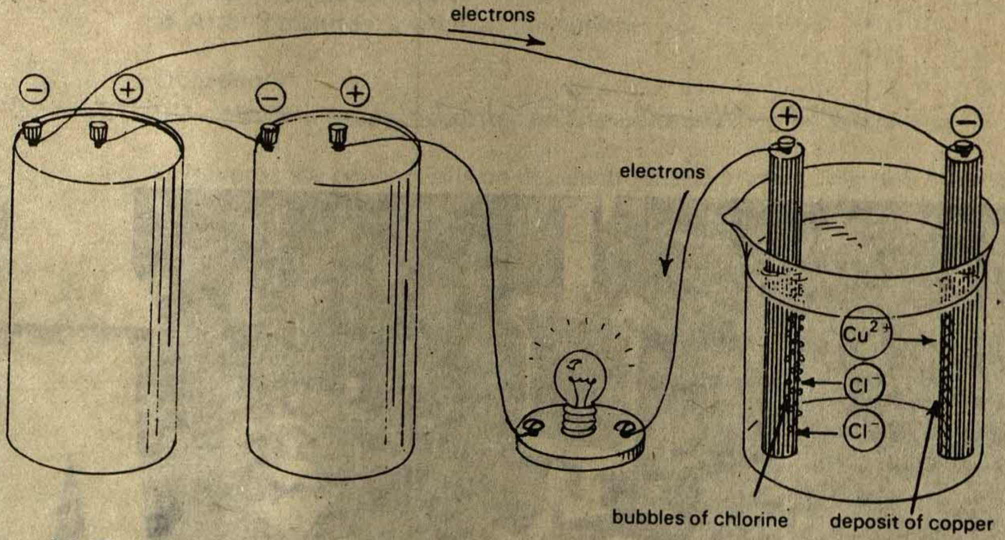


**Figure 9.3:** The electrolysis of copper chloride solution. The copper ions, being positive, are attracted to the negative electrode. There they receive electrons and become copper atoms. The chloride ions, being negative, are attracted to the positive electrode. There they give up electrons and become chlorine ions.

EXPERIMENT *Testing various liquids to see whether they conduct electricity*

9.1

**Each group will need:**

- small beaker
- 3 volt battery, or power pack
- small lamp in holder, to suit voltage used
- pair of carbon or stainless steel electrodes
- connecting wire
- solutions of acids, alkalis and salts
- methylated spirits, kerosene, petrol, sugar solution

**What to do**

- Connect up the apparatus as shown in figure 9.1.
- Pour some distilled water into the beaker. Stand the electrodes in the water and note whether the lamp bulb lights.
- Remove the electrodes and replace the water with a solution of sodium chloride. Stand the electrodes in the solution. Note whether the bulb lights.
- Remove the electrodes and wash them in clean water.
- Empty the beaker, wash it and add another liquid.
- Tabulate your results, putting down two ticks if the bulb lights brightly, one tick if it lights faintly and a cross if it does not light at all.

| Liquid tested for conductivity | Result |
|---|---|
| | |

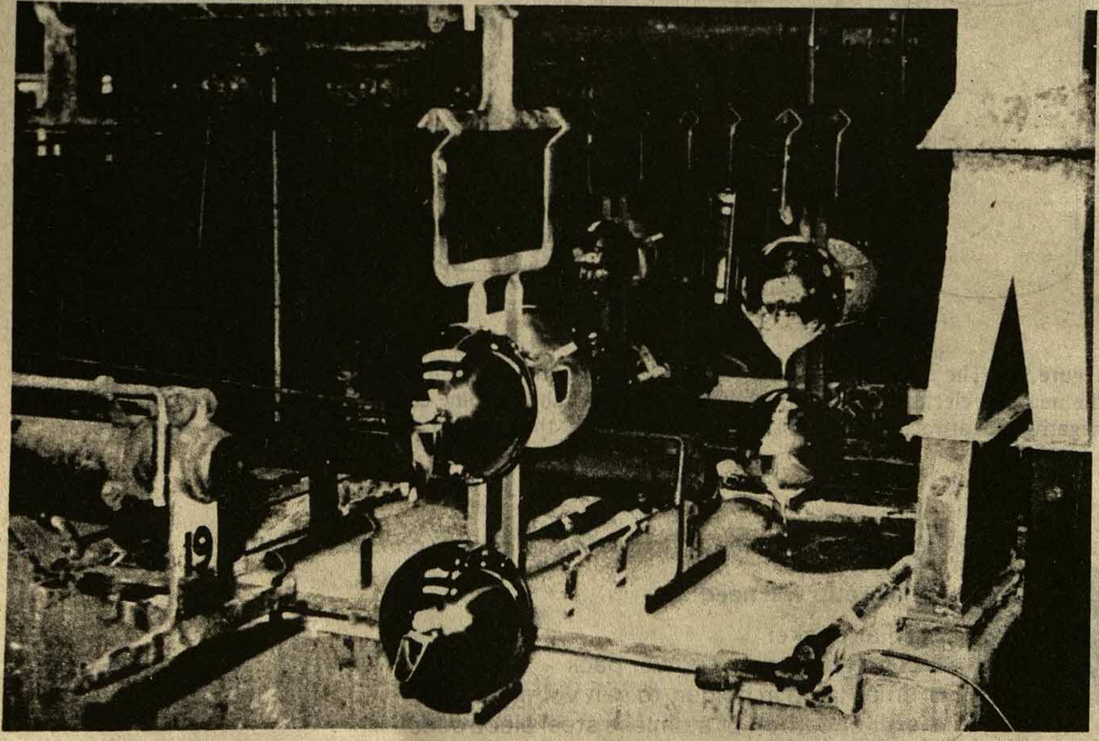


**Figure 9.4:** Electroplating kettles with nickel. The electrolyte is a salt of nickel. The kettles are immersed in the solution and travel through it on a conveyor belt. The conveyor belt is connected to the negative terminal of the power supply. (Photo courtesy Sunbeam Corporation Ltd)

**EXPERIMENT 9.2**

*What happens when you reverse the current during electroplating?*

**Each group will need:**

- pair of carbon electrodes
- beaker
- solution of copper sulphate
- battery or power pack
- switch
- wire

**What to do**

- Connect up the apparatus in the same way as shown in figure 9.1, but with the lamp replaced by a switch.
- Pour copper sulphate solution into the beaker. Insert the electrodes and switch on the current.
- After 2 minutes, switch off the current.

**Question**

9.1 Was any copper deposited on an electrode? If so, on which one?

- Reverse the connections on the electrodes so that the anode is changed to the cathode and vice versa.
- Switch on the current for 2 minutes.

**Question**

9.2 What happened to the copper deposit on the carbon when the current was reversed? Did you notice anything else happening on the electrodes?

## Electrolytes

1. Electrolytes when dissolved in water conduct electricity.
2. Acids, alkalis and salts are electrolytes.
3. Solutions of electrolytes contain ions.
4. Ions are particles charged with electricity.
5. During electrolysis positive ions move to the cathode and negative ions move to the anode.

## Spelling list

anode
cathode
conductivity
electrolysis
electrolyte
electroplate
ion
terminal

## Things to do

**9.3** Test the conductivity of molten substances. Use a hard glass test tube and a pair of small stainless steel electrodes fitted to an insulating strip. Place some crystals of sodium nitrate in the test tube. Stand the electrodes in the dry salt. Does the lamp light? Melt the crystals over a Bunsen flame, then test the conductivity again. Can you explain the result? Test various solids, such as potassium bromide, potassium chloride, naphthalene and butter.

## More questions

**9.4** What is an electrolyte? Name six electrolytes and six non-electrolytes.

**9.5** Name the electrolyte used in car batteries. (R)

**9.6** What is an anode? What is a cathode?

**9.7** What is an ion?

**9.8** How can we show that the particles of copper in copper chloride solution are positively charged ions?

**9.9** What do you understand the word "electrolysis" to mean?

**9.10** It is required that the frame of a toaster be electroplated with nickel. The frame is submerged in a solution of a nickel salt. To what terminal would you connect the frame?

**9.11** State the law for the attraction and repulsion of electric charges.

**9.12** Neither dry soil nor pure water will conduct electricity. Yet wet soil will conduct electricity. Explain why this happens.

**9.13** By passing an electric current through a piece of freshly milled timber, merchants are able to estimate quickly the amount of sap it contains. How can this be done, when neither dry wood nor water conducts electricity?

**9.14** A sample of water, advertised as distilled water, is suspected of being tap water. What test would you use to solve your problem?

## Test yourself (chapter 9)

Answer each of the questions 1 to 5 by choosing one word or name from the list on the right and writing it in your workbook.

| | |
|---|---|
| 1. Name an electrolyte.<br>2. Name an electrode that attracts positive ions.<br>3. Name a non-electrolyte.<br>4. Name a substance that sets free positive ions when dissolved in water.<br>5. Name the electrode connected to the negative terminal of the battery during electrolysis. | sugar<br>potassium nitrate<br>copper<br>anode<br>negative<br>cathode<br>zinc<br>positive |

In answering questions 6 to 8, choose the best answer and write its letter in your workbook.

6. Which one of the following groups contains only electrolytes?
   (a) potassium sulphate, dilute nitric acid, naphthalene
   (b) copper, sodium hydroxide, potassium nitrate
   (c) sodium chloride, sugar, dilute sulphuric acid
   (d) potassium nitrate, magnesium chloride, potassium sulphate.

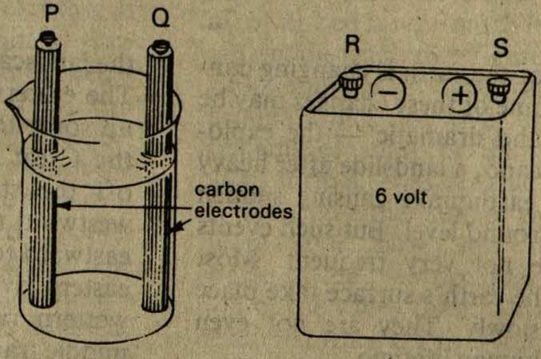


**Figure 9.5**

7. The above diagram shows a beaker containing a solution of copper chloride and two carbon electrodes. A battery is on the right.
   In order that P may be plated with copper,
   (a) P must be connected to R and Q to S.
   (b) P must be connected to Q and R to S.
   (c) P must be connected to S and Q to R.
   (d) P and Q must both be connected to R.
8. In the electrolysis experiment in question 7, if P were plated with copper, the anode would be
   (a) P
   (b) Q
   (c) R
   (d) S.

# 10

# The landscape

The surface of the earth is changing continuously. Some of these changes may be devastating and dramatic — the explosion of a volcano, a landslide after heavy rain, or an earthquake causing sudden changes in ground level. But such events as these are not very frequent. Most changes in the earth's surface take place very, very slowly. They are not even noticed in a human lifetime.

This chapter deals with these slow changes and describes some of the landforms that they produce.

## What causes slow changes in the landscape?

There are two main processes that form the landscape — erosion and earth movement. In most cases these work against each other — erosion wearing the surface down and earth movements lifting it up. Geologists have estimated that, if it were not for the forces of uplift, erosion would wash most of the continents into the seas within 25 million years.

Erosion is the wearing away of the land surface by agents that weather and remove soil and rock. It occurs at the earth's surface. Earth movements, on the other hand, have their origins beneath the earth's surface. These movements may lift, lower, tilt, fold or fracture the earth's crust.

Figure 10.1 shows the main features of the landscape in south-eastern Australia. The eastern part of Australia was lifted up some ten million years ago, to form the Great Dividing Range. Rivers flow off the steep slopes of this range — westward towards the inland plains and eastward towards the Pacific Ocean. The eastern rivers are much shorter than the western rivers, and flow faster in the middle tracts.

In the western part of New South Wales, the two main rivers are the Darling and the Murray. These rivers wind

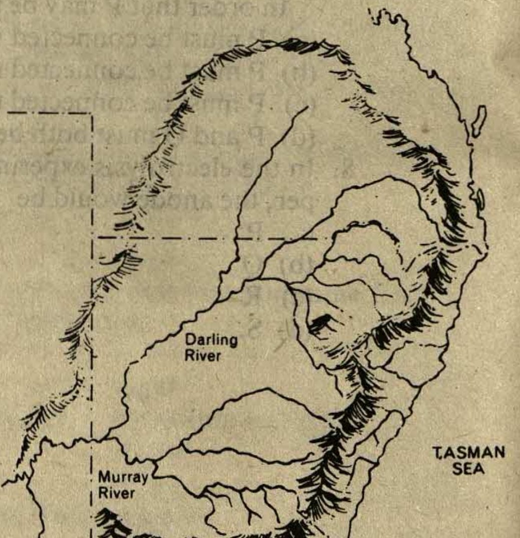


**Figure 10.1:** Main features of the landscape in south-eastern Australia.

slowly over flat plains in a generally westward direction, finally emptying into the Indian Ocean in South Australia.

## River landforms

When a region of the earth's surface is pushed upwards, streams begin to flow down the slopes. If you have ever seen a mountain stream in flood you will appreciate the eroding power of the surging, muddy water. It is not so much the water itself that wears away the rock, but the grinding action of the sand, pebbles and boulders that the water carries. The faster the flow, the more rapid is this action. If the speed of a stream is doubled, the size of the pebbles it can move along is increased 60 times.

Because the gouging power of a river depends so much on its speed, we would expect the landforms along a river to be different as we travelled down its length. This is indeed so. These different landforms can be divided into upper, middle and lower tracts.

### Upper tract

This is the section where the river flows fastest. It quickly wears channels through the rocks. The water takes the easiest way down, curving round obstacles in its path. This leads to the formation of a winding course and the development of overlapping spurs, as shown in figure 10.2.

The valleys are usually V-shaped and are formed by the wearing-down action of stones and boulders carried by the stream. However, in rocks resistant to weathering steep-sided gorges may result.

### Middle tract

Headwater streams (streams in the river's upper tract) flow swiftly down their steeply graded valleys, joining other streams in their downward passage. As a rule, they emerge on to a wide valley with rounded hills on either side. Here the river slows, because the fall of its bed is now much less. The river is in middle tract. (See figure 10.3.)

Flooding has produced alluvial plains, through which the river slowly winds. Remains of some of the earlier flood plains form a series of large steps, called terraces, on either side of the river. (See figure 10.6, page 96.) The winding course of the river occupies only a fraction of the valley floor. This course may be altered when the river is in flood.

The wide valley of a river in its middle tract is carved out over a period of millions of years. The spurs that overlapped when the valley was in its upper tract stage are gradually worn right back during periods of intense flooding.

### Lower tract

In the lower part of a river's course, the fall of the bed is very gradual, sometimes only a few centimetres per kilometre. As a result the river flows very slowly. Near its exit to the sea, the river is said to be in coastal tract. Flowing over a plain, the river is said to be in plains tract.

It must not be thought that because a river is moving slowly it carries very little silt. The slow-moving Mississippi River, for example, carries 37 500 tonnes of debris per hour. This is equivalent to 25 trains, each of 30 trucks, with every truck carrying 50 tonnes.

Whenever there is a big flood in a river's lower tract, the river spreads out over the adjoining plains, depositing enormous amounts of silt. Some of this silt is dropped close to the channel as the water spills over, thus forming levee banks. Subsequent floods may break through these banks and change the river's course.

When not in flood the river meanders in a tortuous path similar to that shown in figure 10.4. At Cowanna, the town shown in this photograph, a person can travel fourteen kilometres along the Murray River and then be only 200 metres from his starting point.

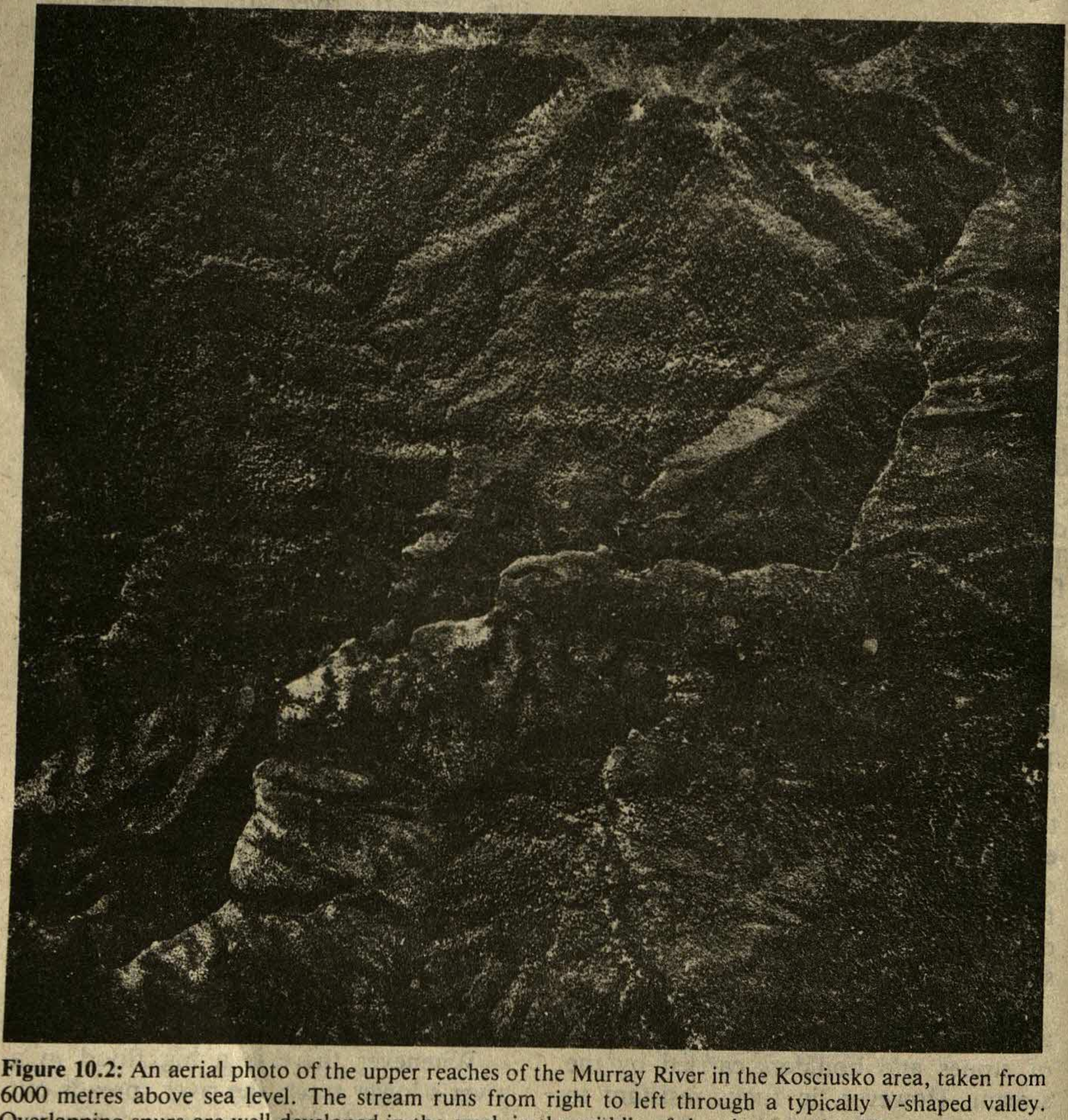


**Figure 10.2:** An aerial photo of the upper reaches of the Murray River in the Kosciusko area, taken from 6000 metres above sea level. The stream runs from right to left through a typically V-shaped valley. Overlapping spurs are well developed in the creek in the middle of the photograph. (Photo courtesy the Undersecretary for Lands, New South Wales)

## River deltas

Rivers, except for those that become lost in deserts, finally flow into the sea or into a lake. Here the water is gradually brought to a halt, which causes it to drop the sediments it is carrying. These sediments accumulate on the sea or lake floor in layers. The larger sediments settle first, close to the river mouth, while the finer sediments settle further out. Thus a fan-shaped deposit may be formed. This spreads out from the river mouth and is called a delta. (See figure 10.5, on page 95.)

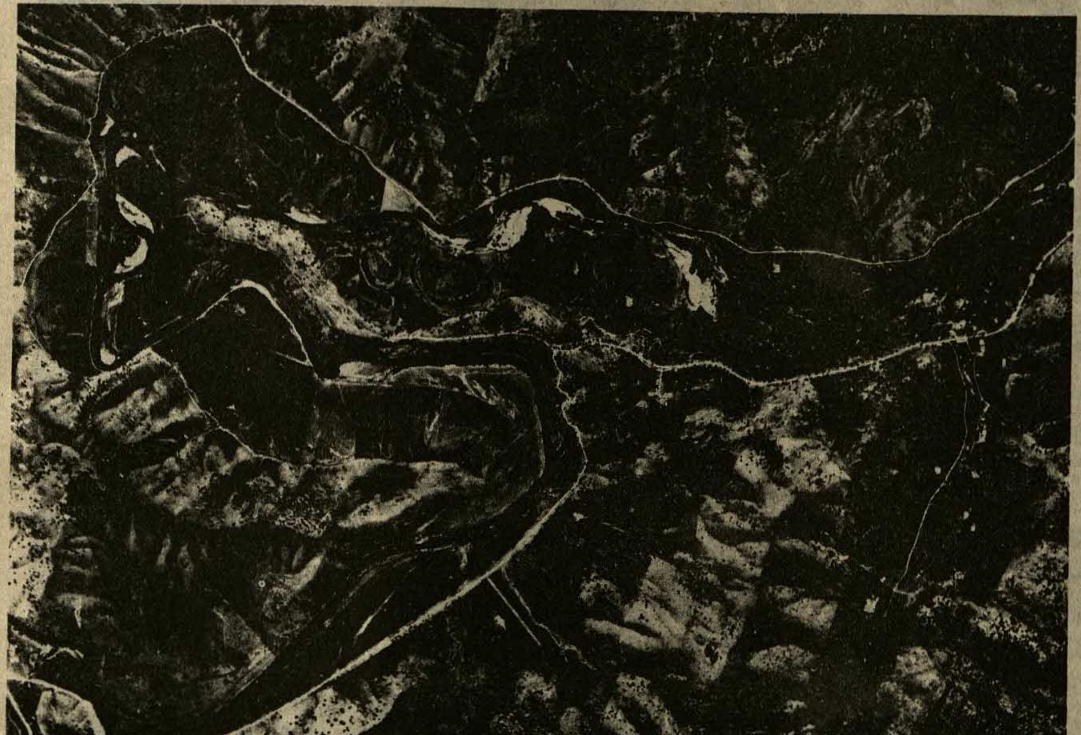


**Figure 10.3:** An aerial photo of the Murray River about 80 kilometres upstream from Albury, taken from 6000 metres above sea level. The river, in its middle tract, runs from right to left through a wide, winding valley. The width of this valley is roughly marked by the roads on either side. Note the deposits of sand on the inside of the river bends, and the smaller lakes on the river flats. (Photo courtesy the Undersecretary for Lands, New South Wales)

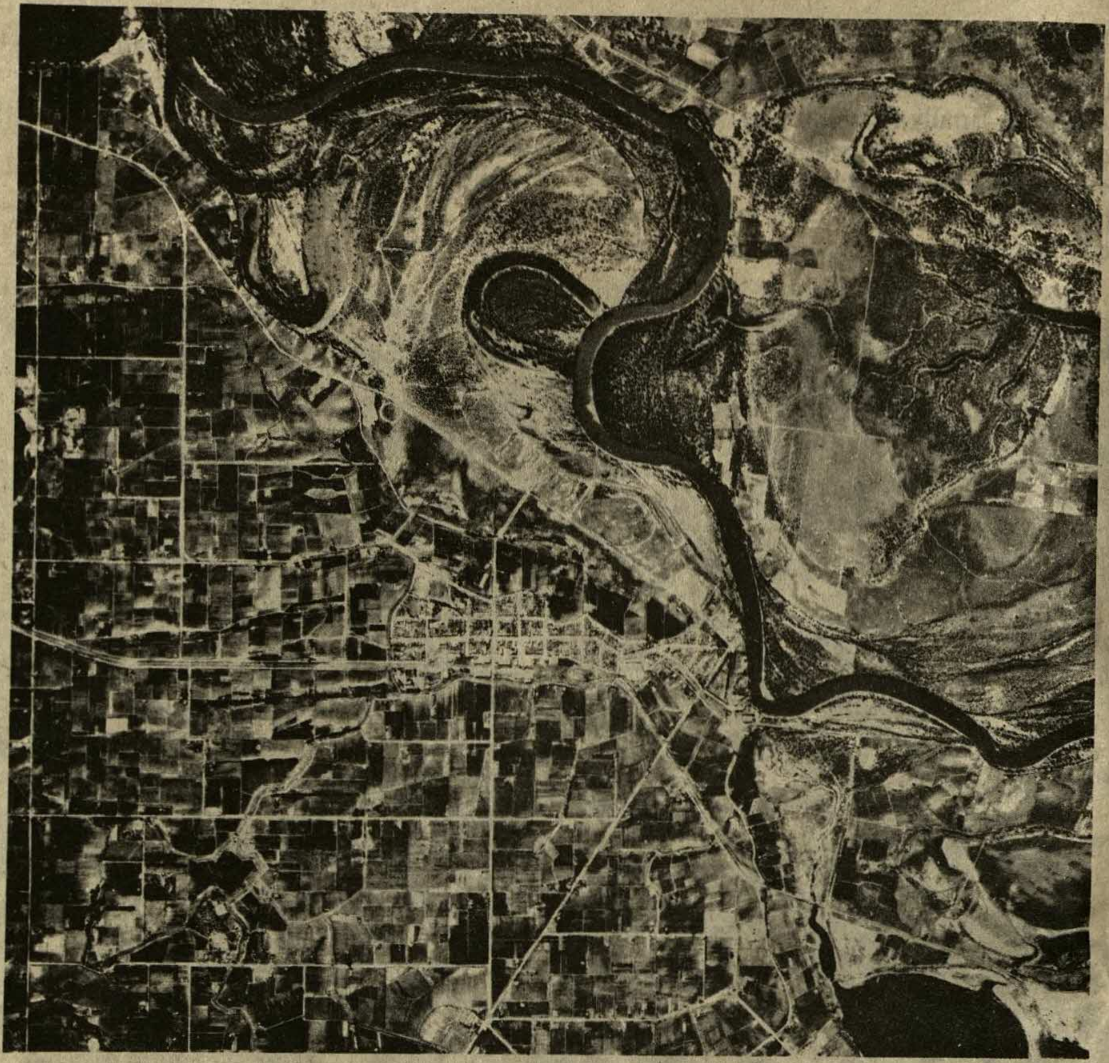


**Figure 10.4:** An aerial photo of the Murray River at Cowanna near Mildura, taken from 7000 metres above sea level. The river runs from right to left through flat, open country. The roads along the river are built close to the flood banks on either side. Note the billabong in the middle of the photo and the large loop in the river channel at the top left-hand corner. (Photo courtesy the Undersecretary for Lands, New South Wales)

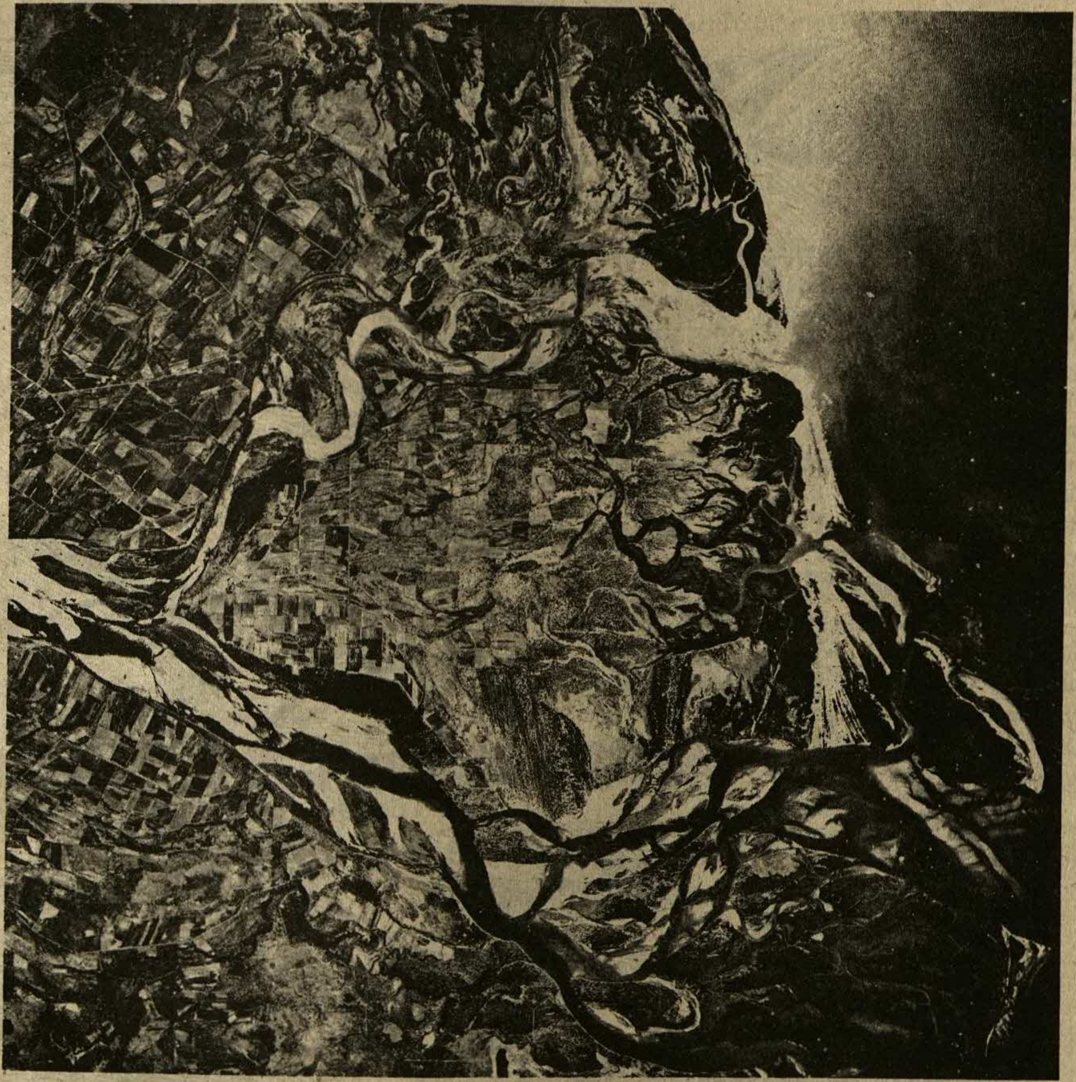


**Figure 10.5:** An aerial photo of the Burdekin River delta in Queensland, taken from 7600 metres above sea level. The river branches into a number of courses through the roughly fan-shaped delta. (Photo courtesy the Director of National Mapping, Department of National Development, Canberra)

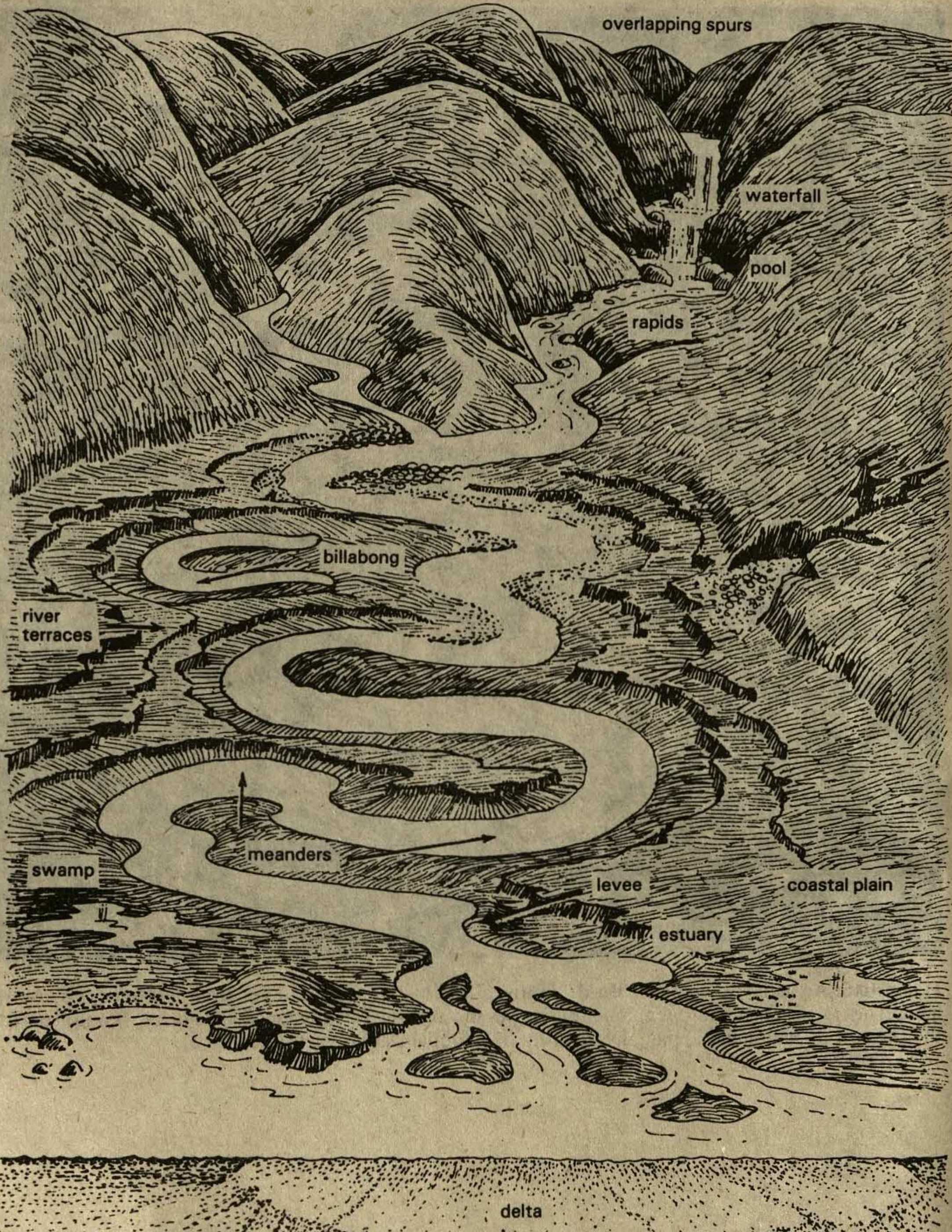


**Figure 10.6:** Diagram showing river landforms along a river from its upper tract to the coast.

A delta may, over a period of millions of years, be changed by compaction and other processes into beds of sedimentary rock.

## Desert landforms

Deserts are areas with less than 25 centimetres of rainfall per year. Such an area is the Great Western Plateau of Australia, shown in figure 10.7. This is an immense area of land raised some 450 to 600 metres above sea level. It occupies much of Western Australia and parts of the Northern Territory and South Australia.

On the plateau there are wide expanses of flat country, broken in places by extensive ranges. The plateau includes both the hottest and the driest parts of the continent. It is often referred to as Australia's inland desert. As a rule, there is little vegetation and the land surface is therefore largely exposed to the weather. The rocks are subject to extreme temperature changes and as a result tend to shatter, due to expansion and contraction. Loose material may be removed by flash floods or blown about by the wind.

The following are some of the landforms resulting from these conditions.

### Mesas and inselbergs

The plateau and its ranges are gradually being eroded away. Running water from the rare flash floods removes much of the weathered material. The rest is removed by the wind. As a result of erosion, flat-topped hills may become separated from the plateau. These hills are called mesas. The flat tops are due to hard cappings of rock, which have resisted erosion more than did the surrounding rocks.

Other, well-rounded rocks rise steeply out of the desert in places. These are inselbergs. Ayers Rock is a good example. The hardened sandstone of this rock resists erosion more than does the surrounding country.

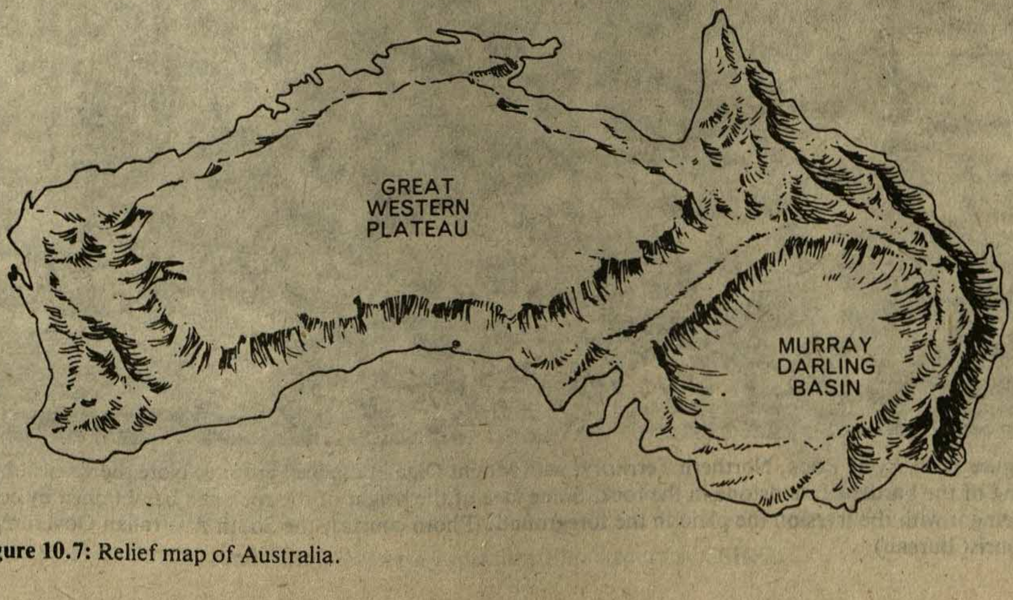


**Figure 10.7:** Relief map of Australia.

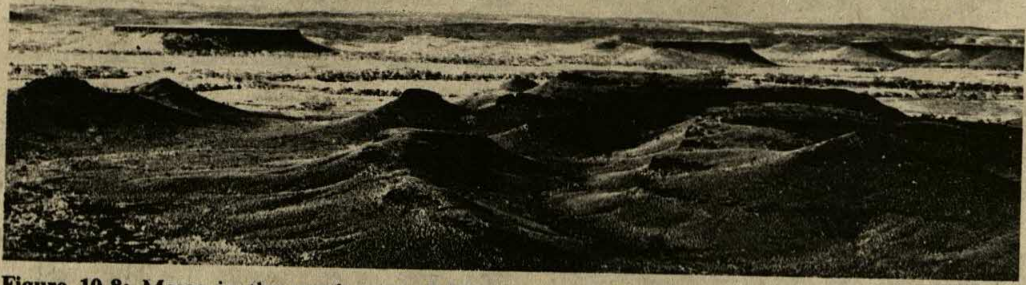


**Figure 10.8:** Mesas in the north-west of Western Australia. These mesas were originally part of the Kimberley Plateau. (Photo courtesy Department of Industrial Development, Western Australia)

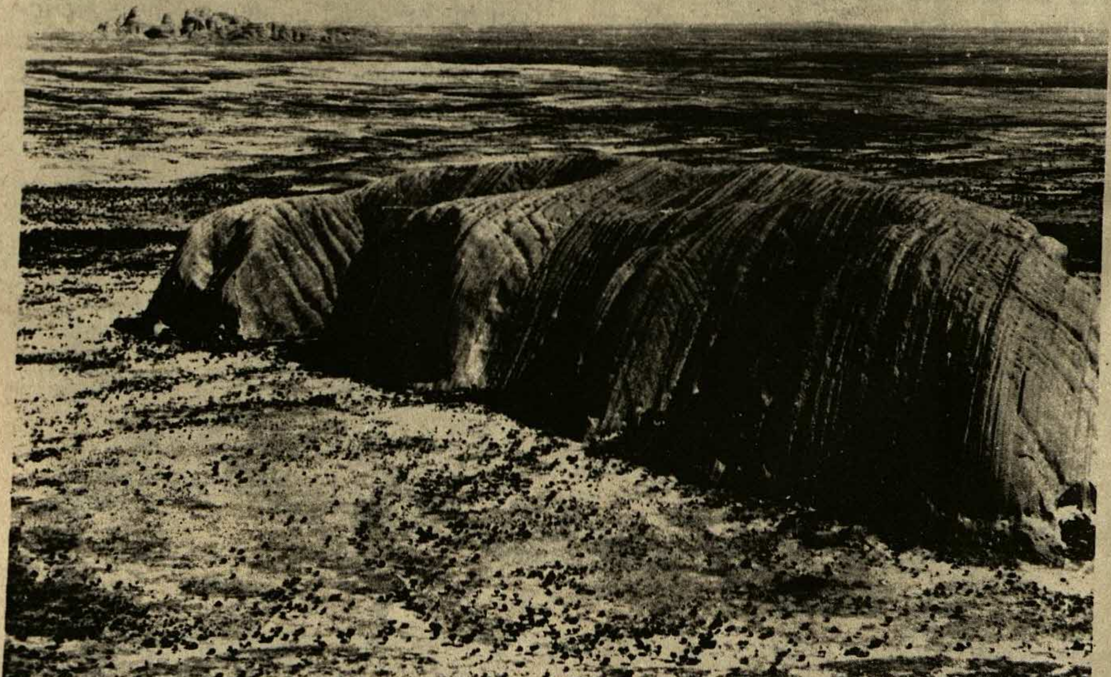


**Figure 10.9:** Ayers Rock, Northern Territory, with Mount Olga in the background. Note the vertical bedding of the hardened sandstone in the rock. Some idea of the height of the rock can be obtained by comparing it with the trees on the plain in the foreground. (Photo courtesy the South Australian Government Tourist Bureau)

## Sand dunes

Sand picked up by the wind is dropped when the wind speed falls. The slightest mound of sand may hinder the next wind and more sand may be deposited. Dunes are thus built up. They have long windward slopes and steep leeward slopes. (See figure 10.10.) Dunes shift slowly across the desert as sand is blown from the windward slopes and dumped over the leading edges. Small dunes usually develop a crescent shape and are called barchans.

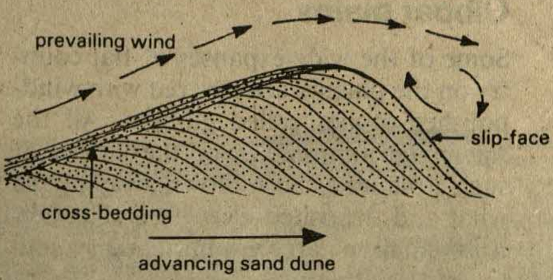


**Figure 10.10:** A sand dune moving slowly under the influence of the prevailing wind. It has a long, gentle slope on the windward side and a short steep slope on the leeward side.

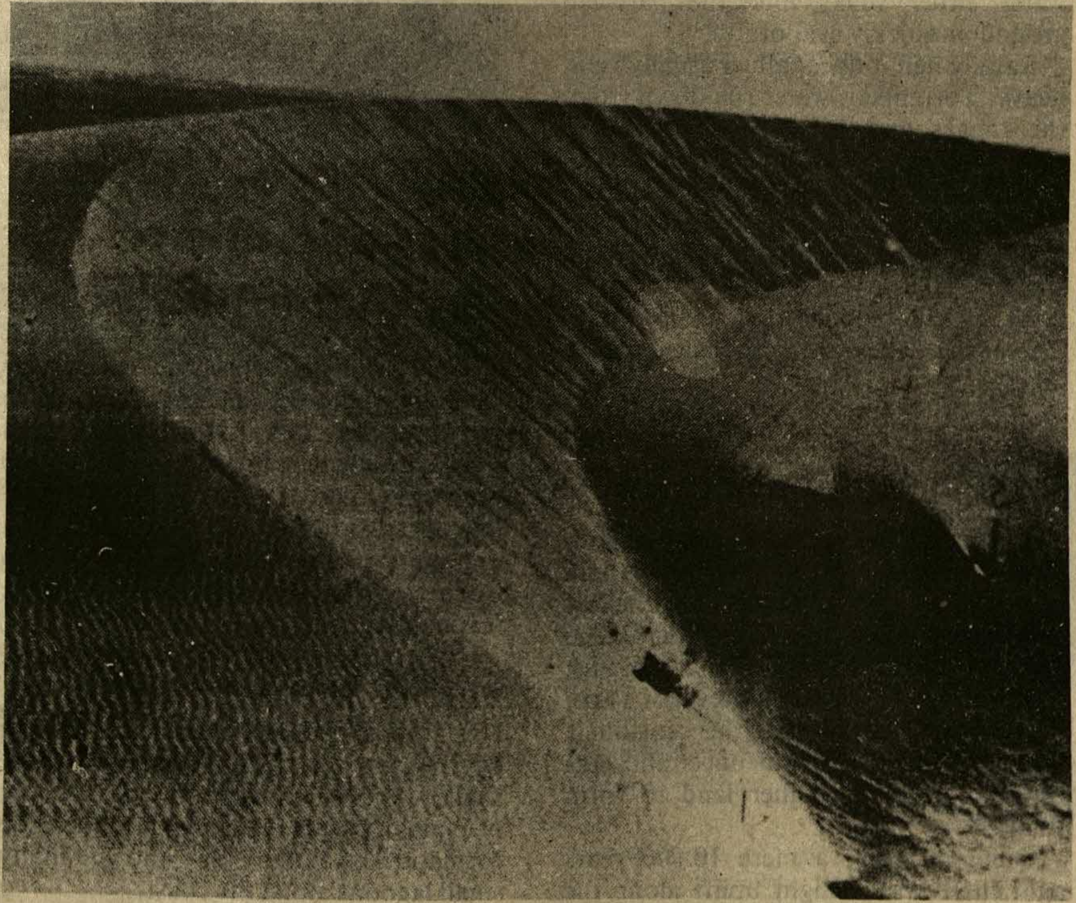


**Figure 10.11:** A shifting sand dune in Western Australia. (Photo courtesy CSIRO)

## Gibber plains

Some of the wide expanses of flat country on the plateau are covered with wind-polished stones called gibbers. All the fine material originally on the surface of such a plain has been blown away by the wind and deposited elsewhere. The gibbers remaining are very hard and strongly resist weathering.

## Salt lakes

Rainfall on the plateau is low and also very intermittent. There are no permanent rivers and even the temporary streams disappear very quickly. The water either soaks into the parched ground or quickly evaporates.

Rain, when it does fall, is usually very heavy. Torrents of water run down from the ranges and off the edges of the plateau. They spread out over the plains, dividing into many little streams. Rarely do these streams reach the sea. Often they run into depressions and form shallow lakes. When these dry up, a crust of salt remains on the lake bed. These salt lakes are also called playa lakes.

# Coastal landforms

The earth is believed to be 5000 million years old. During this long time there have been a number of ice ages; the last one ended about 15 000 years ago. The melting ice of this particular ice age caused a gradual rise in sea level of about 30 metres. This flooded the coastlines, entering valleys to form inlets and cutting off areas of higher land to form islands.

Quite recently, a mere 10 000 years ago, there was a slight uplift along the east coast of Australia. The following features are the result of these two happenings.

## Drowned river valleys

These are long deep inlets from the sea formed by the flooding mentioned above. Sydney Harbour and Broken Bay, on the coast of New South Wales, are excellent examples.

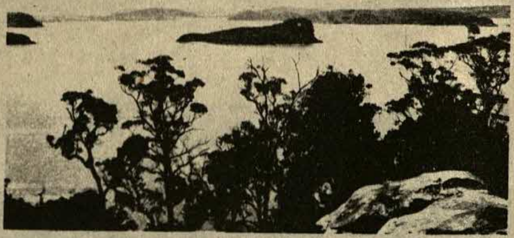


**Figure 10.12:** Lion Island in Broken Bay, New South Wales. Broken Bay is a drowned river valley.

## Tied islands and sand spits

Many of the islands formed off the coast of New South Wales by the rising water have since been rejoined to the coast by the development of connecting sand spits. The slight uplift of the land 10 000 years ago assisted this process. Barrenjoey Head is joined to Palm Beach by a thin sand spit and Long Reef is joined to Collaroy in a similar manner. These features are called tied islands.

## Shallow bays and lagoons

Not all of the inlets formed in flooding by the sea are deep. Many are quite shallow and were formed by the flooding of plains. This is the explanation for the formation of Botany Bay and the many small lagoons along the coast.

The recent uplift, and silting up by

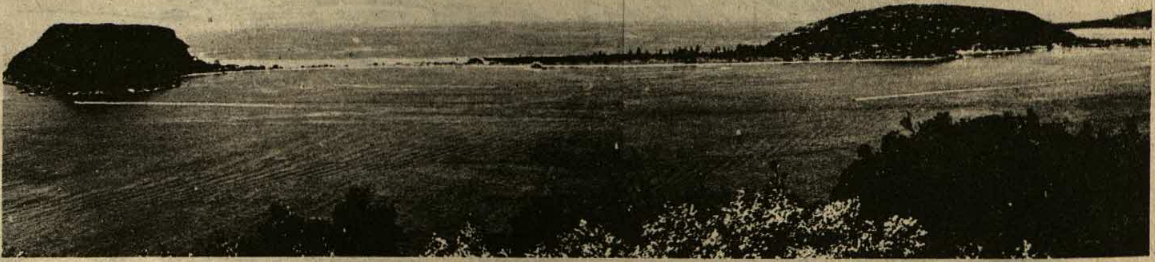


**Figure 10.13:** A tied island, Barranjoey Head, at the entrance to Broken Bay in New South Wales. The head is tied to Palm Beach, on the right, by a thin sand spit.

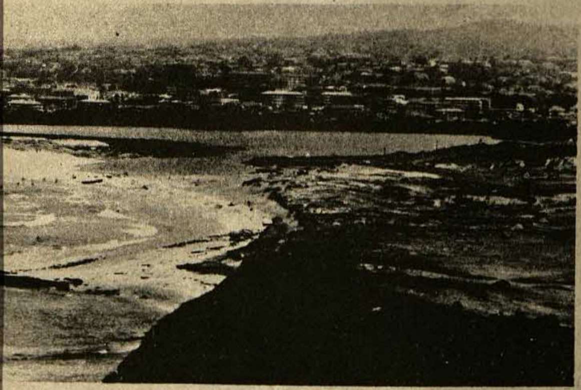


**Figure 10.14:** Dee Why lagoon in New South Wales. At the time the photograph was taken the opening to the sea was closed.

streams, have made these bays and lagoons even shallower. The openings of the lagoons to the sea are almost closed off by bars of sand. These have been formed by waves dumping sand as they lose speed.

## Exposed rock platforms

Sea waves contain tremendous amounts of energy — especially during storms. It is this energy that tears down headlands by wearing away the rock at the base. Yet ten metres or so beneath the level of the sea, all is relatively still, even during a storm. It is for this reason that underwater platforms are formed; the rock below sea level is relatively unaffected by the waves even though the cliffs above are being worn away.

Many of these rock platforms are exposed along the coast of New South Wales. They have been exposed by the uplift that occurred about 10 000 years ago.

Figure 10.16, on the next page, shows a variety of coastal landforms.

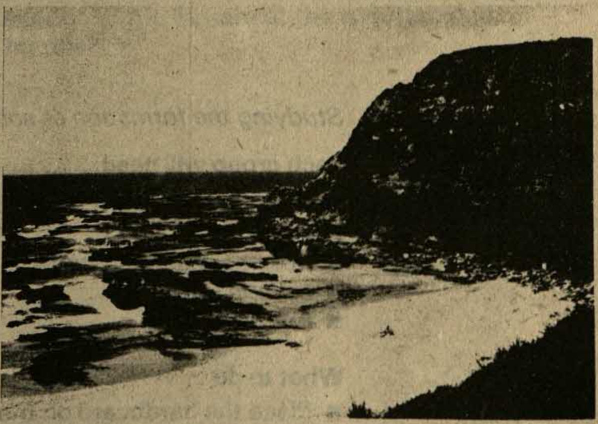


**Figure 10.15:** The rock platform at the southern headland of Turimetta Beach in New South Wales. The photograph was taken at low tide. At high tide the platform is completely covered.

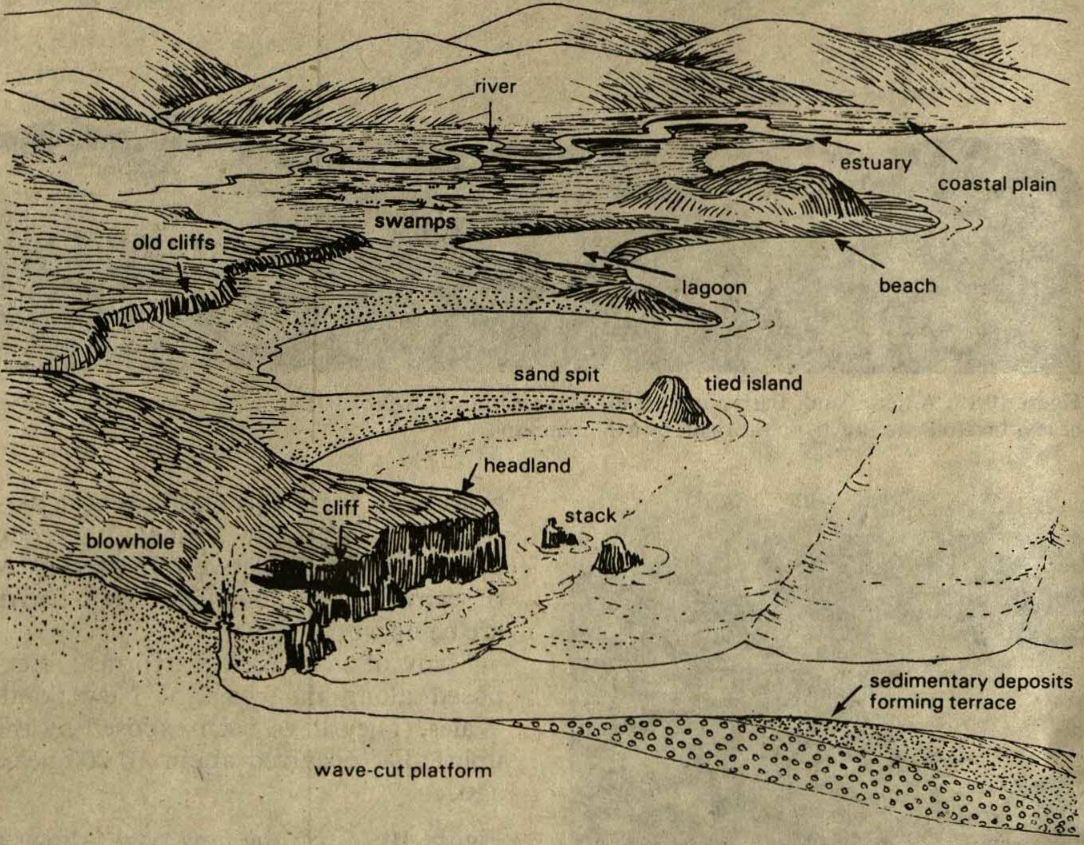


**Figure 10.16:** Landforms that may occur along a coastline.

**EXPERIMENT 10.1**

### *Studying the formation of some river landforms*

**Each group will need:**

- piece of hardboard about 2 × 1 metres
- sand or soil
- hose connected to tap
- several bricks
- broom handle

**What to do**

- Place the hardboard on the ground with one end slightly raised by bricks.
- Cover it with sand or soil to a depth of several centimetres.
- Form a straight channel in the sand down the board by pressing the broom handle into it.
- Direct a gentle flow of water down the channel.

**Questions**

**10.1** Did the channel remain straight? If it did not, describe the path worn by the water.
**10.2** Describe the nature of the banks on any bend in the stream.
**10.3** Describe the delta formed by the stream. Which sediments were carried furthest by the water?

**EXPERIMENT 10.2**

*Investigating a section of coastline*

The excursion selected is along the coast of New South Wales between Sydney and Broken Bay. However, any other section of coastline will serve equally well. If another area is visited, figure 10.16 will act as a guide to the features to be looked for. Take a pencil and notebook, and perhaps a camera, on the excursion.

Refer to figure 10.17 (next page). The numbers on this map refer to landscape features that can be seen on the excursion.

Make notes on the excursion that will enable you to answer the following questions fully.

**Questions**

**10.4** Draw up a table listing the numbers 1 to 16. Opposite each number write the name of the kind of landscape feature to which it refers.
**10.5** How do lagoons differ from drowned river valleys?
**10.6** Why are there exposed rock platforms along this section of the coast?
**10.7** Do you think there may have once been a lagoon behind Bilgola Beach? Explain your answer.
**10.8** Give an explanation for the formation of the tidal swamp in Pittwater (feature no. 13).
**10.9** Do you think the narrow passage between the island in Pittwater and Church Point is deep or shallow? Give reasons for your answer.
**10.10** The openings of the two lagoons to the sea are at the northern end. Can you suggest a reason for this?

## Spelling list

alluvial
channel
crescent
delta
dune
fissure
gibber
inselberg
island
lagoon
leeward
levee
meander
mesa
plateau
resistant
silt
spur
terrace
torrent
tortuous
tract
windward

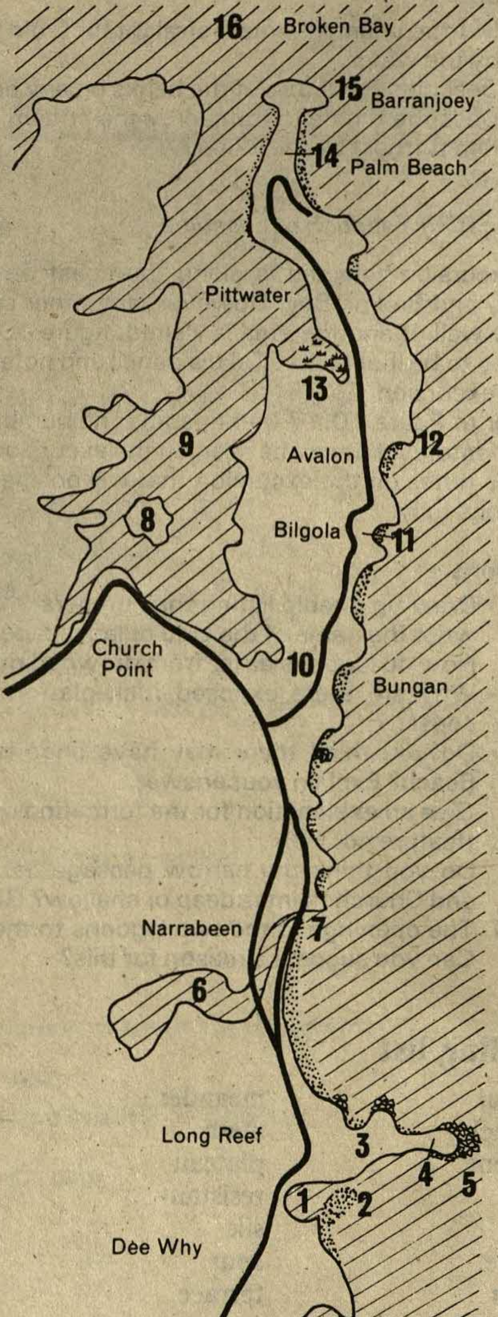


**Figure 10.17:** Map of Sydney coastline between Dee Why and Broken Bay.

## The landscape

1. Some processes forming the landscape are
   - erosion due to wind or running water
   - earth movements lifting, lowering, tilting, folding or fracturing the crust
   - the reduction of ice caps by melting, causing a rise in sea level; at other times, the expansion of ice caps, causing a fall in sea level
   - deposition of sediments when the speed of wind or moving water falls.

**Landforms**

2. Running water produces
   - streams in upper, middle and lower tract
   - river deltas
   - alluvial fans in desert areas
   - mesas
   - inselbergs.
3. Wind produces
   - gibber plains
   - sand dunes.
4. Evaporation produces
   - salt lakes.
5. A rise in sea level produces
   - drowned river valleys
   - shallow bays and lagoons.
6. Uplifts produce
   - ranges
   - plateaus
   - exposed rock platforms.

## Things to do

**10.11** Most homes have a collection of photographs or slides. Go through one such collection picking out those photos that show examples of the landforms discussed in this chapter.

**10.12** Refer to books in your library that contain photos of national parks. Try to name each landscape feature illustrated.

## More questions

**10.13** Why is the erosive work of running water much more effective during periods of flood?

**10.14** Why is the erosive work of the wind much more effective in very hot, dry areas?

**10.15** Explain briefly how river deltas are formed.

**10.16** Why do rocks that are subjected to extreme temperature changes tend to shatter?

**10.17** How are rock platforms formed by the sea?

**10.18** Explain how each of the following features is formed:

- sand dunes
- salt lakes
- lagoons
- exposed rock platforms.

**10.19** Which is the more effective agent of erosion in the desert areas of Australia — wind or running water?

**10.20** Compare rivers in their upper, middle and lower tracts by copying and completing the following table.

| | Upper tract | Middle tract | Lower tract |
|---|---|---|---|
| (a) shape of the valley | | | |
| (b) fall of the river bed | | | |
| (c) speed of the water | | | |
| (d) number of tributaries | | | |
| (e) volume of water delivered | | | |
| (f) kinds of debris carried | | | |
| (g) rate of erosion | | | |

**10.21** Figure 10.5 (page 95) has a very light patch at the top. Give an explanation of this. At what time of the day do you think the photograph was taken?

## Test yourself (chapter 10)

1. Match the words and phrases in the left-hand column with the most suitable word or words from the right-hand column. Write the answers in your workbook.

| | |
|---|---|
| (a) Banks standing well back from the course of a meandering river.<br>(b) V-shaped valley.<br>(c) A flat expanse of wind-polished stones.<br>(d) A flat expanse of exposed rock at the base of a cliff on the coast.<br>(e) A rocky island in the middle of a harbour.<br>(f) A billabong.<br>(g) Coastal lagoon. | delta<br>gibber plain<br>waterfall<br>lagoon<br>upper tract<br>levees<br>raised sea level<br>middle tract<br>sand dune<br>raised rock platform |

In answering questions 2 to 5, choose the best answer and write its letter in your workbook.

2. It is most likely that the sand on an ocean beach between two headlands
    - (a) crystallized from the sea water
    - (b) was always there
    - (c) came from the breakdown of rocks
    - (d) spreads across the entire ocean floor.
3. In a fast flowing stream, you would be most likely to find deposits of
    - (a) mud
    - (b) pebbles
    - (c) sandstone
    - (d) silt.
4. Of the following landforms, the one that is a typical feature of the lower tract of a river is
    - (a) narrow V-shaped valleys
    - (b) a delta
    - (c) waterfalls and rapids
    - (d) overlapping spurs.
5. In a coastal region where raised rock platforms exist, you would also expect to find
    - (a) drowned valleys
    - (b) deltas
    - (c) tied islands
    - (d) coastal lagoons.

# 11

# Sedimentary rocks

Over 90 per cent of the rocks exposed on the earth's surface are sedimentary. They have been formed by the pressing together and hardening of material that came from other rocks. They may also have been produced from living things. In this chapter we will study the different sorts of sedimentary rocks and the ways in which they are formed.

## Mechanically formed rocks

During erosion, weathered rock or soil is removed by agents such as running water, wind or moving ice. Sedimentary rocks that form from solid particles moved by these agents are said to be mechanically formed.

### Action of running water

Some of the material removed from rocks and soil by running water goes into solution. Most of it, however, is insoluble. If this insoluble material is very fine, like clay or silt, it is carried in suspension by the stream. If it is coarse, it may be rolled along the bottom.

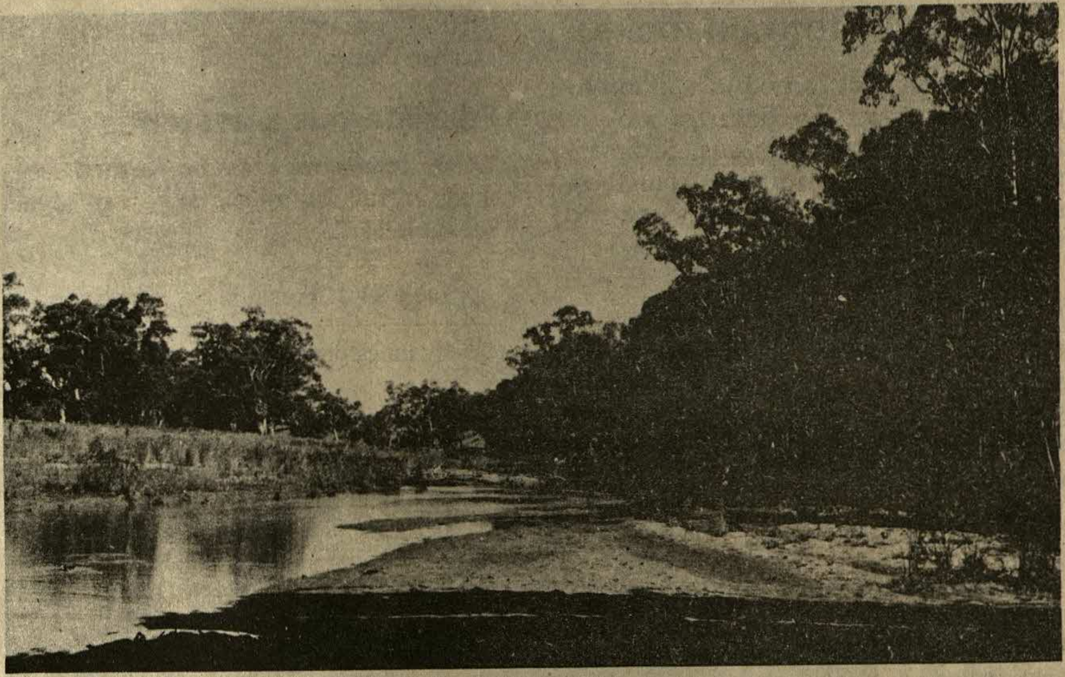
As the water loses speed, the stream begins to drop its load, forming layers of sediment. These layers, if undisturbed, eventually form sedimentary rocks. The process may require thousands of years. The names given to these rocks depend on the size of the fragments in the rocks. See table 11.1.

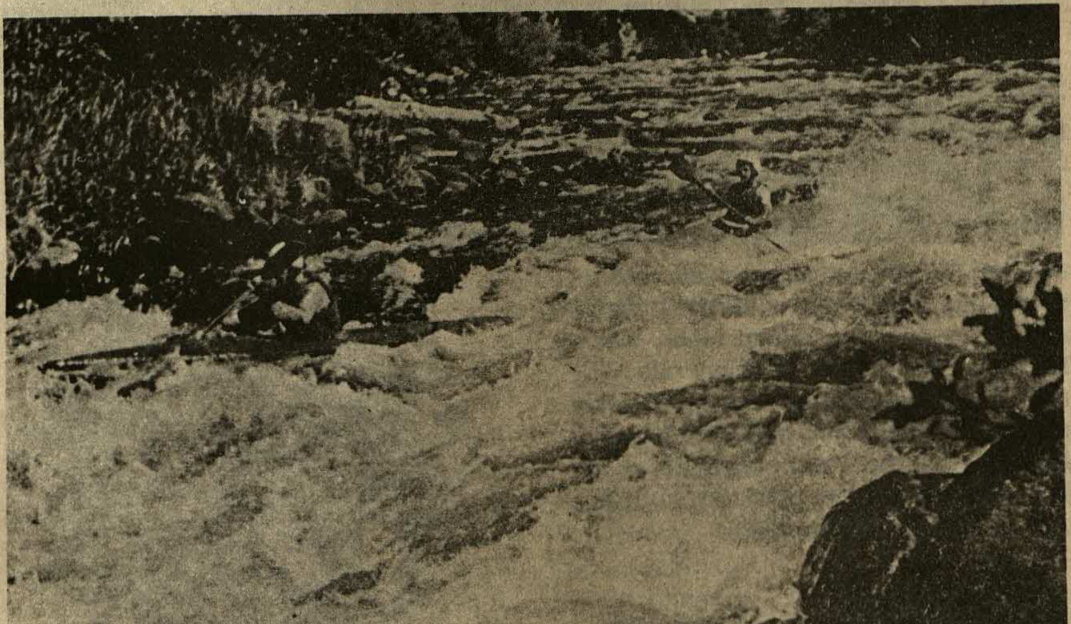
**Table 11.1:** Sedimentary rocks formed by the action of running water

| Name of rock | Largest fragment in the rock |
|---|---|
| coarse conglomerate | boulder (over 25 cm) |
| conglomerate | cobble (6 – 25 cm) |
| fine conglomerate | pebble |
| sandstone | sand |
| siltstone | silt (very fine sand) |
| shale or claystone | clay (about $\frac{1}{400}$ mm) |

### Action of wind

Another mechanically formed rock is loess. The sediment in loess consists of very fine fragments blown into place by the wind. Many deposits of loess are found in China. The material forming the rocks is thought to have come from the plains of Siberia.





**Figures 11.1 and 11.2:** These photographs show two different rivers. What sort of rock fragments would each river carry?

## Chemically formed rocks

The rock material carried in solution by running water may be converted back into solids by chemical means. Sedimentary rocks may be formed from these solids; two examples are limestone and rock salt.

### Limestone

Calcium carbonate is a salt that is insoluble in water. However, it dissolves slowly in water containing carbon dioxide. When this happens a solution of calcium hydrogen carbonate is formed.

calcium carbonate + water + carbon dioxide → calcium hydrogen carbonate

Evaporation of this solution causes carbon dioxide to escape. At the same time fine crystals of calcium carbonate are formed.

calcium hydrogen carbonate → calcium carbonate + water + carbon dioxide

Limestone rock is composed of masses of these fine crystals. Thus limestone formed in this way is a chemically formed rock.

### Rock salt

A large proportion of rock salt consists of the mineral sodium chloride. It forms as a layer over dry inland lakes, which fill only during times of heavy rain. The rainwater dissolves the sodium chloride out of the rocks and soil over which it flows. When the water evaporates as the lake dries up, the salt crystallizes out as a crust on the bed of the lake.

## Organically formed rocks

These are rocks formed from living things. They include fossiliferous ("fossil-containing") limestone, coal and petroleum.

### Fossiliferous limestones

These limestones may be formed from shells, corals or by the action of algae. See table 11.2.

**Table 11.2:** Fossiliferous limestones

| | |
|---|---|
| Shelly limestones | Contain shell fragments from dead organisms such as molluscs |
| Coral limestones | The remains of ancient coral reefs |
| Algal limestones | Formed from the hard parts or skeletons of some types of algae. These algae make their skeletons from the carbon dioxide and calcium salts that they draw from the water. |

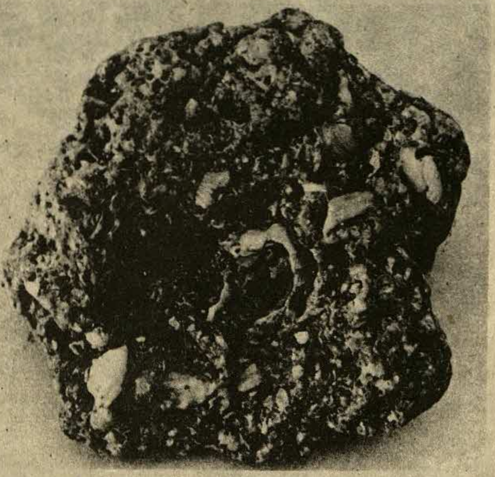


**Figure 11.4:** A piece of fossiliferous limestone found on the coast of Florida, U.S.A. Notice the shells and shell fragments, which are cemented together with calcium carbonate and sand.

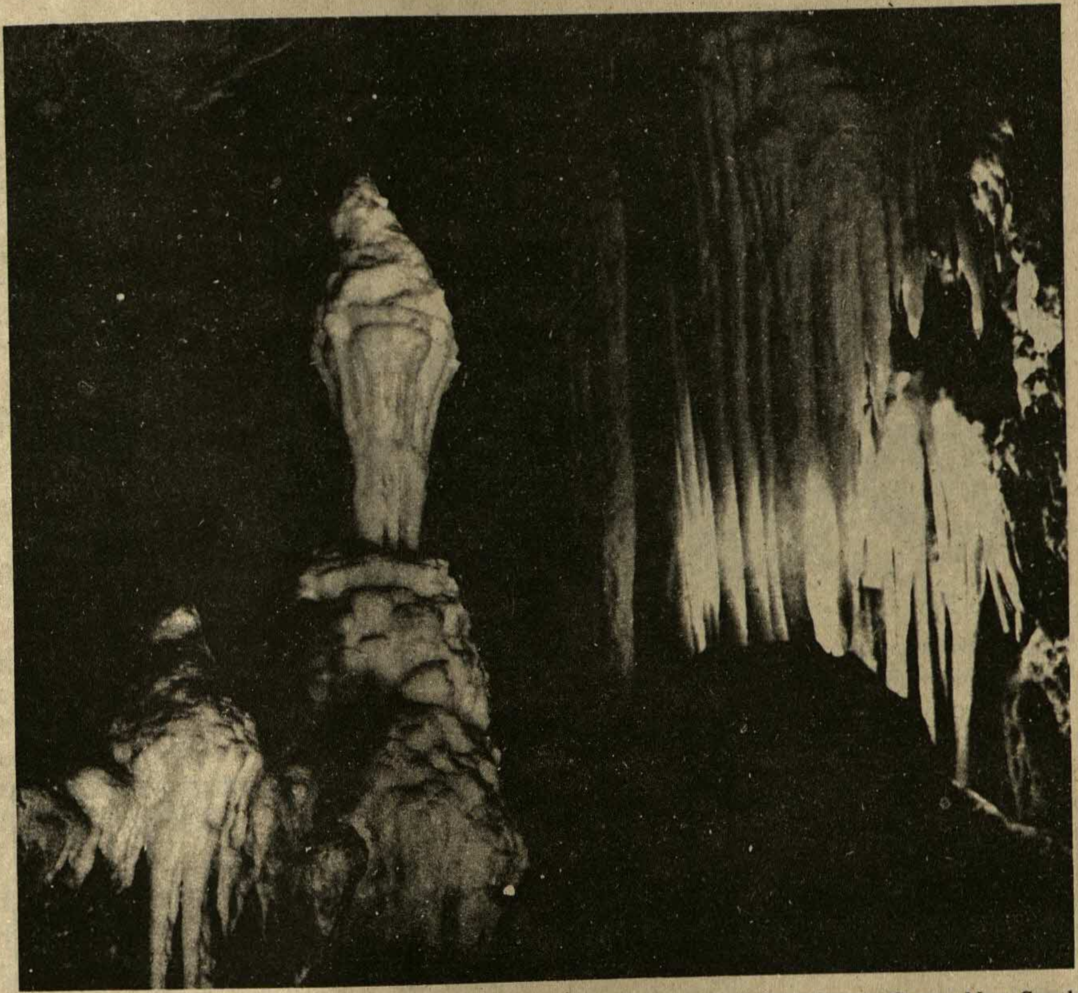


**Figure 11.3:** The "Lot's Wife and Cockatoo" limestone formation at Wombeyan Caves, New South Wales. The limestone in the formation is a chemically formed sedimentary rock. (Photo courtesy New South Wales Department of Tourism)

## Coal

Coal is formed from the remains of plants that grew in swamps. To be preserved the vegetation must be buried rapidly. (This is the case with any animal or plant matter that is to be preserved in rocks.) Rapid burial prevents decay by oxidation and stops attack by those bacteria that need air to survive.

The buried vegetable matter is first converted into peat. This is done by bacteria that do not need air. The peat itself is then changed by the pressure of overlying sediments. Temperature increase due to the depth of burial assists these changes. The first change is into brown coal, the next into black coal and the final stage is the formation of anthracite.

As these changes in the coal proceed,

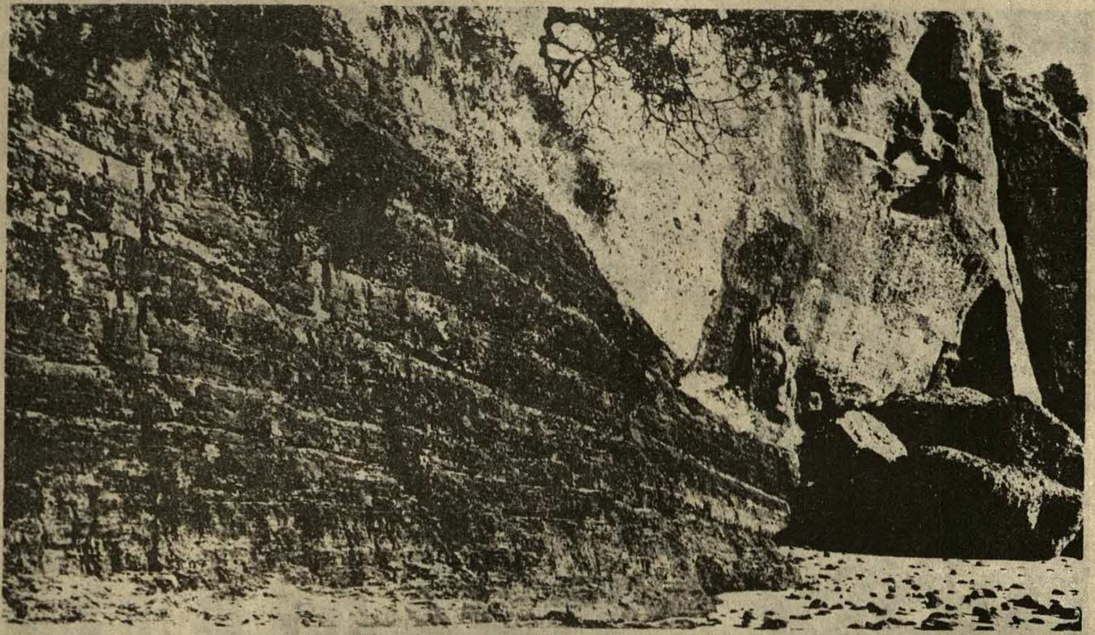


**Figure 11.5:** Outcrop of the Great Northern Coal Seam at Catherine Hill Bay, New South Wales. (Photo courtesy Joint Coal Board)

**Table 11.3:** Peat and coal

| Coal | Appearance | Percentage of carbon | Moisture content | Comments |
|---|---|---|---|---|
| Peat | dark in colour, sometimes fibrous, with plant fragments visible to naked eye | very low | very high | burns only when dry |
| Brown coal | fibrous structure, no plant fragments | low | high | mined in Victoria by open-cut methods |
| Black coal | black and dense, laminated | high | low | many varieties mined in New South Wales and Queensland |
| Anthracite | hard, black, brittle, with metallic shine | very high | very low | no true anthracite mined in Australia |

over a period of millions of years, the percentage of carbon in the coal gradually increases. This increase is due to a loss of moisture and gases as the pressure increases. Anthracite, with a very high percentage of carbon, is called a high rank coal. Brown coal, on the other hand, with a low percentage of carbon, is called a low rank coal. Table 11.3 gives some properties of peat, brown coal, black coal and anthracite.

## Petroleum

Petroleum is formed in sedimentary rocks from the remains of certain plants and animals. Scientists believe that the petroleum is formed by bacteria acting on these remains in the absence of air.

The name petroleum covers all those natural solids, liquids and gases that contain compounds called hydrocarbons. A hydrocarbon contains the elements hydrogen and carbon only. Octane is a liquid hydrocarbon; its chemical formula is $C_8H_{18}$.

## How sedimentary rocks are formed

The following processes are the main ones by which sediments are converted into sedimentary rocks.

*Compaction*. As the layers of sediment build up, those at the bottom are subjected to great pressure. This pressure pushes the rock fragments closer together and squeezes out much of the water that was in the sediments. This process is called compaction.

*Cementation*. The fragments in sedimentary rocks may be held together in several ways:

- by clay particles that when pressed close together stick to each other and to other fragments in the rock
- by minerals crystallizing from solution in the spaces between the fragments. The common minerals that do this are calcium carbonate, silica and the iron oxides. (See experiment 11.3.)

## Reading the rocks

The type of rock found in an area can often tell us something about the conditions that existed in that area when the rock was formed. The following are a few examples.

*Conglomerate*. This rock contains some fragments at least 6 centimetres across. Only fast running water (or ice) could roll such large fragments along. (There will be other clues if it was ice.) The presence of conglomerate therefore suggests that at the time it was laid down the terrain was mountainous, with fast flowing streams. The conglomerate, however, may have been laid down well away from the mountainous country, in places where the streams slowed down.

*Shale*. All the grains in shale are extremely fine. They settle out of suspension only when the water carrying them is moving very slowly and without turbulence. If the shale was laid down in freshwater (there may be other clues to this), the local terrain must have been very flat for the water to be moving so slowly. If the shale was laid down in sea water, it must have been well away from any currents or wave action. Shales have often been deposited in lagoons and on continental shelves.

*Coral-reef limestone*. Warm shallow seas are needed for the growth of coral. The tiny polyp cannot survive in any other environment. The Great Barrier Reef, off the Queensland coast, shows how successfully coral grows under these conditions. The occurrence of limestone formed from ancient coral reefs indicates that shallow tropical seas once existed in the area.

*Coal*. The occurrence of coal indicates former swampy conditions. There are two main theories on the formation of coal. According to one theory the coal is formed where the vegetation grew. This is the "in place" theory. According to the other theory, rafts of coal-forming vegetation are moved to another place by floods washing into the swamp. This is the "drift" theory.

Many coal seams have clays underneath with roots penetrating from the coal seam into the clay. This evidence supports the "in place" theory. Other coal seams show evidence of the vegetation having been moved. Some, for example, show the remains of tree trunks with roots pointing up. This evidence supports the "drift" theory. Geologists now believe that coal is formed in both these ways. New South Wales coal seams contain coal formed mainly from drifting vegetation.

## Variations found within sedimentary rocks

Sedimentary rocks are not the same throughout. Some of the variations in them are due to changes in conditions at the time of formation. The following features are some examples.

*Laminations*. Nearly all sedimentary rocks are laid down in layers or strata. (Se figure 11.6.) One layer may differ from the next in either grain size or composition. The layers may vary in thickness from a few millimetres to many metres. If a layer is less than one centimetre thick it is called a lamination. Laminations, being thin, nearly always consist of fine material. This fine material is deposited slowly and only if the water is very calm. Claystones are formed on the bottom of still shallow expanses of water. A laminated claystone is called a shale. Each lamination is formed by the settling out of additional fine material washed in by rainfall.

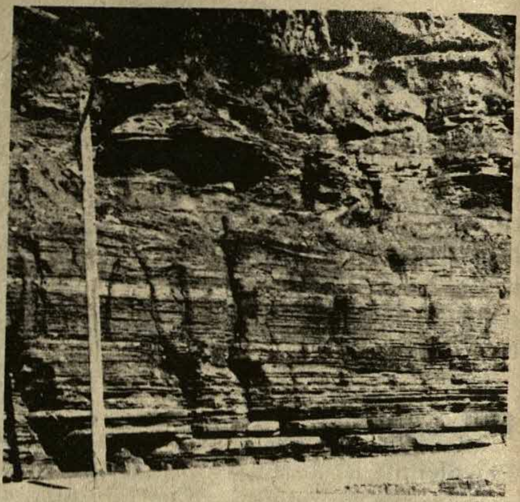


**Figure 11.6:** Headland at the southern end of Bilgola Beach, New South Wales, showing strata, or layers, of sedimentary rock.

*Cross-bedding*. When a current slackens, the larger particles it is carrying may be dropped. These often roll over the edge of the material previously deposited, thus forming a slope. (See figures 11.7a and b.) This slope is at an angle to the direction of the main bedding. The formation of layers at an angle to the main bedding is called cross-bedding. Cross-bedding occurs in streams on the inside of bends, at the front edge of deltas, in front of sand bars and in the front of sand dunes.

*Ripple marks*. Currents and waves can cause ripple marks on the surface of a freshly deposited sediment. These marks, often seen on calm sandy beaches, consist of a series of small parallel ridges. When the water moves backwards and forwards, the ripple

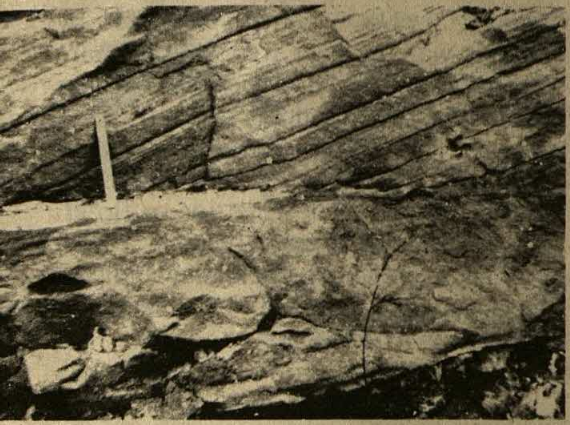


**Figure 11.7a:** Cross-bedding in Hawkesbury Sandstone exposed in a road cutting at Turramurra, New South Wales. Notice the 30-centimetre rule in the photo.

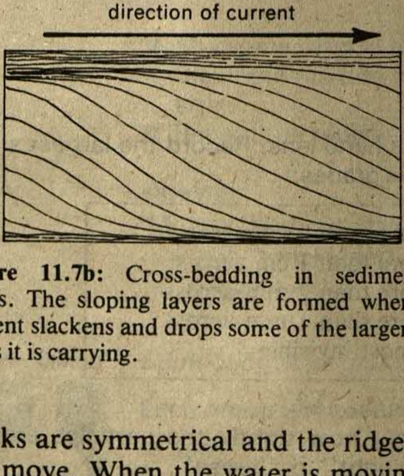


**Figure 11.7b:** Cross-bedding in sedimentary rocks. The sloping layers are formed when the current slackens and drops some of the larger particles it is carrying.

marks are symmetrical and the ridges do not move. When the water is moving in one direction only, the ripple marks are not symmetrical and the ridges move forward gradually. By studying ripple marks in sedimentary rocks geologists can determine something about the conditions existing when the rocks were formed. They can also tell which way was up at the time. For example, if the ripple marks are upside-down, the rocks must have been overturned by earth movements since they were formed.

***Sun cracks***. Mud is a wet mixture of very

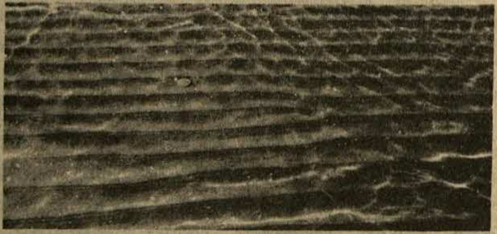


**Figure 11.8a:** Ripple marks in the shallow water of a calm sandy beach at Clareville, New South Wales. Note the 20-cent piece in the photo.

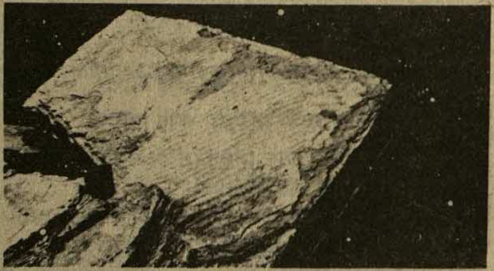
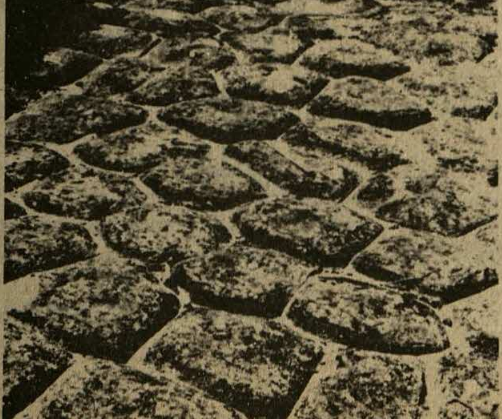


**Figure 11.8b:** Ripple marks in the siltstone block on the rock platform at Narrabeen, New South Wales. Note the small bucket in the photo.

**Figure 11.9:** A tessellated rock pavement in Ku-ring-gai Chase, New South Wales. This sandstone pavement has a regular pattern of sun cracks that have been filled in by clay minerals. Note the 30-centimetre rule in the photo.



small particles. It shrinks considerably as it dries out and as a result cracks are formed. These are often in a regular pattern (see figure 11.9). In sedimentary rocks showing this feature the cracks are filled in by other sediments and stand out clearly. The cracks are wider at the top when formed; rocks containing cracks wider at the bottom must therefore have been overturned some time after their formation.

*Animal tracks.* Footprints left by animals walking over wet sediments are sometimes preserved in rocks. The tracks must be hardened quickly by exposure to the air. This preserves the shape when they are covered by more sediment brought in by a following tide or flood. The presence of animal tracks in a fine-grained sedimentary rock may indicate the existence at the time of formation of mudflats in a tidal zone.

**EXPERIMENT**

**11.1**

*Examining the particles in conglomerate, sandstone and shale*

**Each group will need:**

- samples of conglomerate, sandstone and shale (several of each kind)
- hand lens
- pocket knife or sharp nail
- dilute hydrochloric acid

**What to do**

- Give a number to each sample.
- Examine the various samples with a hand lens. Record the largest size of the particles in each sample. Use five grades:

| | |
|---|---|
| very large | more than 2 cm across |
| large | more than 1 cm across |
| small | more than 2 mm across |
| fine | more than 1 mm across |
| very fine | almost invisible |

- Examine the samples for laminations.
- Use a sharp steel object to find out how tightly the particles are held together. Record as "tight", "fairly tight", or "loose".
- Pour a few drops of hydrochloric acid on to each sample. An effervescence indicates that calcite (calcium carbonate) is one of the cementing materials holding the rock together.
- Tabulate your results.

| Rock examined (type and number) | Size of particles | Any laminations? | How tightly held together? | Any calcite present? |
|---|---|---|---|---|
| | | | | |

**EXPERIMENT 11.2**

### *Examining layering in sediments*

**Each group will need:**

- coarse sand, fine sand and clay
- iron filings
- one-litre measuring cylinder
- fine sieve

**What to do**

- Prepare a mixture of the sand and clay — enough to fill about 200 mL of the measuring cylinder.
- Add the mixture to the cylinder.
- Fill the cylinder with water.
- Place the palm of your hand over the cylinder and invert it several times to thoroughly mix the sediments.
- Stand the cylinder on the bench and allow the sediments to settle.

**Question**

**11.1** Did you notice a layering effect? If so, what kind of sediments were in the bottom layer?

- Mix some sand with about one-tenth of its bulk of iron filings.
- Sieve the mixture so that it is made up of fine particles all about the same size.
- Repeat the sedimentation experiment with the measuring cylinder.

**Question**

**11.2** Was there a layering effect this time? If there was, how do you explain it, considering that all the particles of iron and sand were about the same size?

**EXPERIMENT 11.3**

### *Cementing sand grains to form a rock-like mass*

**Each group will need:**

- sand
- powdered quicklime
- beaker
- two cardboard drinking cups
- glass rod

**What to do**

- If quicklime is unavailable, it may be prepared by heating some builder's lime (calcium hydroxide) strongly.
- Mix sand and a little powdered quicklime in a beaker.
- Add sufficient water to make a thick paste. Stir with a glass rod. Avoid handling the mixture as wet quicklime tends to burn the skin.
- Empty the mixture into a cardboard container. Press down on it with a second cardboard container.
- Allow the mixture to stand for a week.

**Question**

**11.3** At the end of the week, were the sand grains cemented together? Describe the appearance of the "rock".

**EXPERIMENT**

**11.4**

*Examining samples of fossiliferous limestone*

**Each group will need:**

- samples of different fossiliferous limestones
- hand lens
- dilute hydrochloric acid

**What to do**

- Examine each specimen with a hand lens. What colour is it? What is in the rock? Look for shells, shell grit, corals and sand in each specimen. Are there any whole shells, or are they all broken or worn?
- How big are the largest particles in each specimen? Use the grading system you used in experiment 11.1.
- Add a drop or two of hydrochloric acid to each specimen.
- Tabulate your results.

| Rock examined (specimen number) | Appearance | Size of particles | Effect of adding acid |
|---|---|---|---|
| | | | |

## Sedimentary rocks

- Sedimentary rocks generally contain a sediment and a cementing material.
- The sediment may be either mechanically, chemically or organically formed.
- The cementing material may be clay particles or minerals crystallizing from solution.
- The following is a possible sequence in the formation of sedimentary rocks:
  - deposition
  - possible chemical change (as in coal)
  - compaction
  - cementation.

## Spelling list

anthracite
cementation
compaction
conglomerate
crystallize
fossiliferous
lamination
loess
peat
petroleum
ripple
sedimentary
tessellated
turbulence
variations

## Things to do

**11.4** Examine samples of peat, brown coal and black coal. Use a hand lens or binocular microscope. Look for plant remains and laminations. Note whether laminations and plant remains occur together. Tabulate your results.

**11.5** Heat a sample of powdered black coal in a test tube fitted with a short delivery tube. Light the coal gas that is given off. Repeat the experiment using brown coal.

**11.6** Which rock is more closely compacted, sandstone or shale? Select a sample of each small enough to fit into a measuring cylinder. Smear Vaseline over each rock to seal it and measure its volume by displacement of water in the measuring cylinder. Then, separately break up each rock in a tin dish with a hammer and measure the volume of the particles to which the rock is reduced. Which rock showed the greatest difference in volume on the second measurement? This is the one that was more closely compacted.

**11.7** Collect a cupful of beach sand. Spread it out on paper and examine the particles with a hand lens. Can you identify any shell particles? Are there any black particles? Find out what they might be.

**11.8** What will dissolve limestone? Use precipitated chalk for this experiment — it has the same chemical composition as limestone. Make a paste of some of it in a mortar with a little water. Use a little of this paste to make a fine suspension of chalk in water. Bubble carbon dioxide through the suspension. Does the chalk dissolve? How would carbon dioxide get into water in nature? How would it come into contact with limestone? What is its effect on limestone?

## More questions

**11.9** Name the different kinds of rocks that may be formed from sediments deposited by running water.

**11.10** Name a sedimentary rock that may be either chemically or organically formed.

**11.11** Name three organically formed sedimentary rocks.

**11.12** How are unconsolidated sediments converted into sedimentary rocks?

**11.13** Name three common cementing materials in sedimentary rocks.

**11.14** What colour would you expect a rock in which the cementing material is iron oxide to be?

**11.15** What conditions might have existed at the time the following rocks were formed: conglomerate, shale, coral limestone, coal?

**11.16** What are laminations?

**11.17** Explain why cross-bedding may occur in sedimentary rocks.

**11.18** What are ripple marks?

**11.19** How do mud cracks in sedimentary rocks tell us whether the beds have been overturned?

**11.20** Look at figure 11.10. This is a section through some sediments found on the bed of a lake. Explain the events that probably produced this formation.

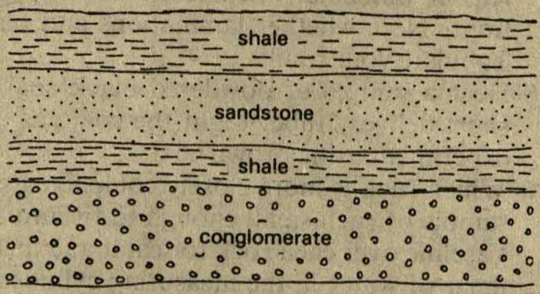


**Figure 11.10**

**11.21** Why is 90 per cent of the earth's surface covered with sedimentary rocks? Think about where the bulk of igneous rocks are formed. Where are sedimentary rocks formed?

**11.22** Would it be possible for sedimentary rock in one place to be weathered, transported, and made into new sedimentary rock in another place? Would there be any difference between the new and the original sedimentary rock?

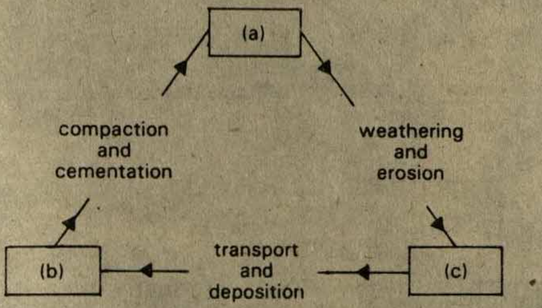
## Test yourself (chapter 11)

1. Answer each of the following by choosing one word from the list on the right.

(a) The hardest mineral commonly found in sedimentary rocks.
(b) A common cementing material found in sedimentary rocks.
(c) A sediment deposited in a lake from a slow-moving river.
(d) The substance present in rain water that enables the water to dissolve limestone.
(e) A sedimentary rock.
(f) The mineral that limestone is mostly composed of.

water
nitrogen
oxygen
calcite
quartz
conglomerate
granite
sand
mud
carbon dioxide

2. Fill in the rectangles in the diagram using the words listed on the right.



sedimentary rock
sediments
rock fragments

In questions 3 to 6, choose the most suitable answer and write its letter in your workbook.

3. Sedimentary rocks are easily recognized because they are
   (a) found only near rivers
   (b) usually in layers
   (c) always composed of quartz grains
   (d) always composed of the mineral calcite.
4. If the river in figure 11.1 was flowing into a lake, it would be depositing there
   (a) silt
   (b) sand
   (c) pebbles
   (d) all of the above.
5. If the river in figure 11.2 was flowing into a lake, it would be depositing there
   (a) silt
   (b) sand
   (c) pebbles
   (d) all of the above.
6. When a river enters a lake, the rock fragments that are carried furthest into the lake will generally be the
   (a) smallest
   (b) largest
   (c) smoothest
   (d) sharpest.

# 12

# Fossils

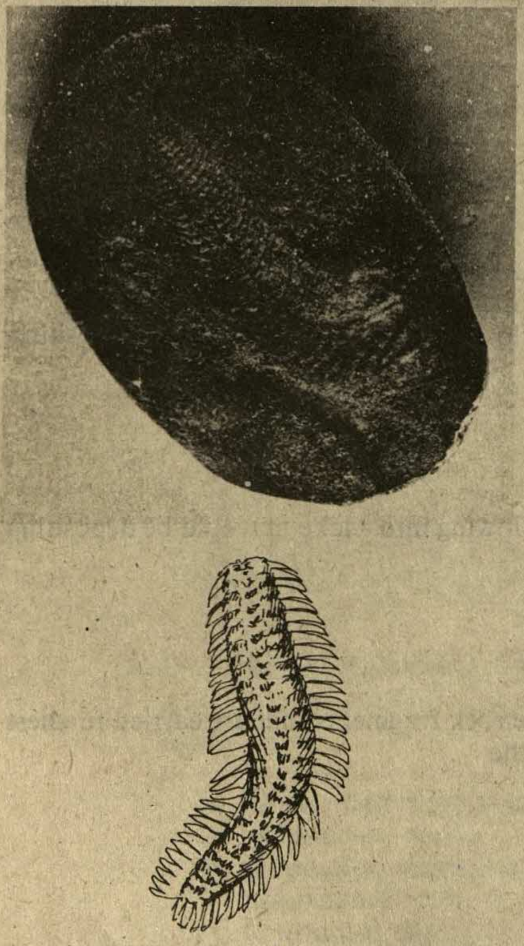


**Figure 12.1:** One of the earliest records of life on earth: the photograph is of a Precambrian fossil of a bristle-worm, which was found in the Flinders Ranges, South Australia. The fossil is over 500 million years old, yet this ancient worm was very much like the beach worms caught by fishermen on the coast of Australia today. The drawing shows one of these modern beach worms.

There are many interesting questions we can ask about the history of the earth. How old is the earth? Has its climate been very different in the past from what it is today? What did the animals of ancient times look like? And, in particular, what did our own early ancestors look like?

There are a number of ways of trying to estimate the age of the earth. One way is to calculate the time taken to form the whole sequence of sedimentary beds that have been deposited, one on top of the other, since erosion first began. This is difficult to do. First we have to examine a number of places where sedimentary rocks are being laid down today. This examination gives us an average of the time it takes a given thickness of rock to form. We then assume that, in the past, all sedimentary rocks have been laid down at this average rate.

Next we have to find a number of places where a large sequence of sedimentary rocks is exposed. One such place is the Grand Canyon, in Arizona. (See figure 12.3.) This canyon, cut out by the Colorado River, is between one and two kilometres deep. There are many beds of rocks exposed in the sides of the canyon. These beds are like the pages of a book telling us about the earth's past. It has been estimated that the walls of the Grand Canyon cover a period of 1000 million years.

Radioactive rocks give us other clues

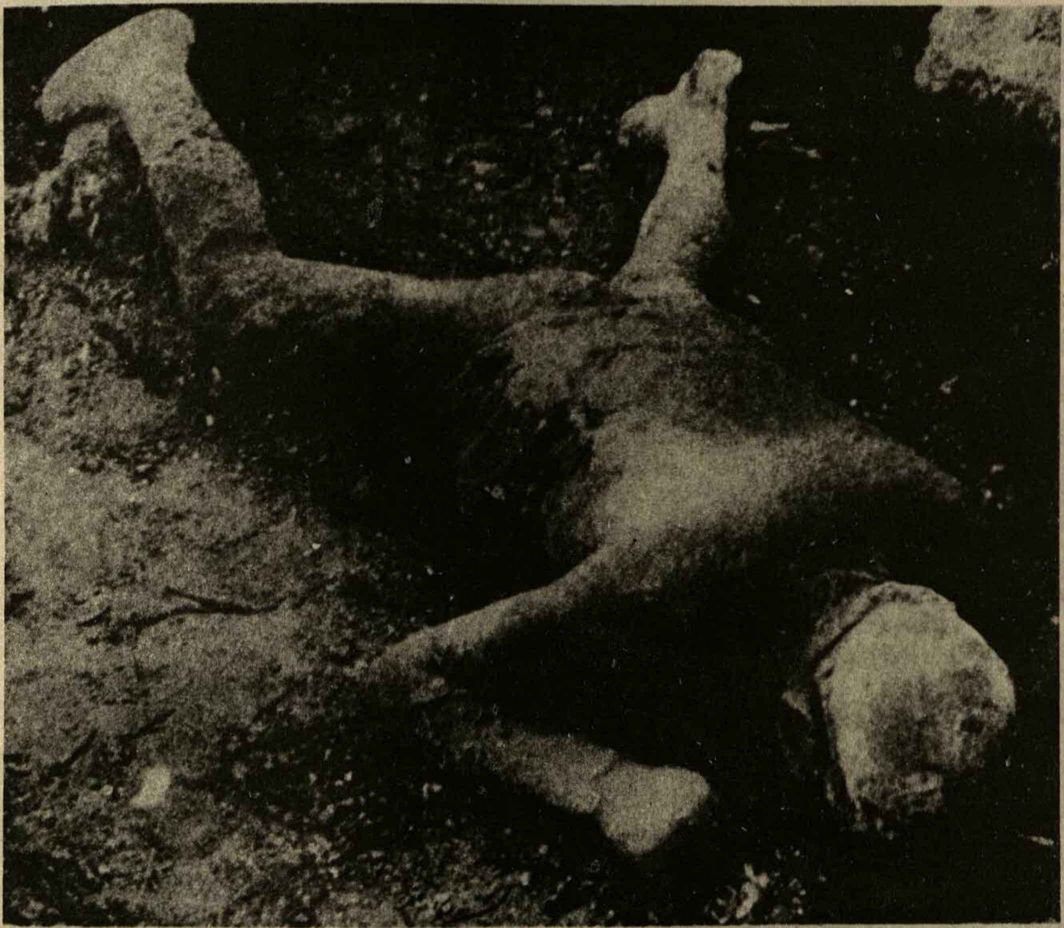


**Figure 12.2:** A fossil cast of one of the victims of the eruption of Mount Vesuvius that covered the Roman city of Pompeii with ash and lava about 2000 years ago. (Photo courtesy Museo Nationale, Naples)

to the age of the earth. For example, uranium, as it emits radioactive rays, changes slowly into other elements. By measuring how much of these other elements are mixed with the uranium we can determine how long the uranium mineral has been in existence, that is, how long since it was formed.

Using these and various other clues, people have estimated that the age of the earth is between 4000 and 5000 million years.

Rocks can also give us information about past climates and ancient animals and plants. For example, coal exists among the rocks of Antarctica. But coal indicates a past tropical climate and densely vegetated swamps. This sort of environment could not have been part of Antarctica as we know it today. Therefore, either there have been remarkable changes of climate, or the Antarctic continent must have moved in some way from the tropics to the pole.

Close investigation of coal beds will sometimes reveal the impressions of

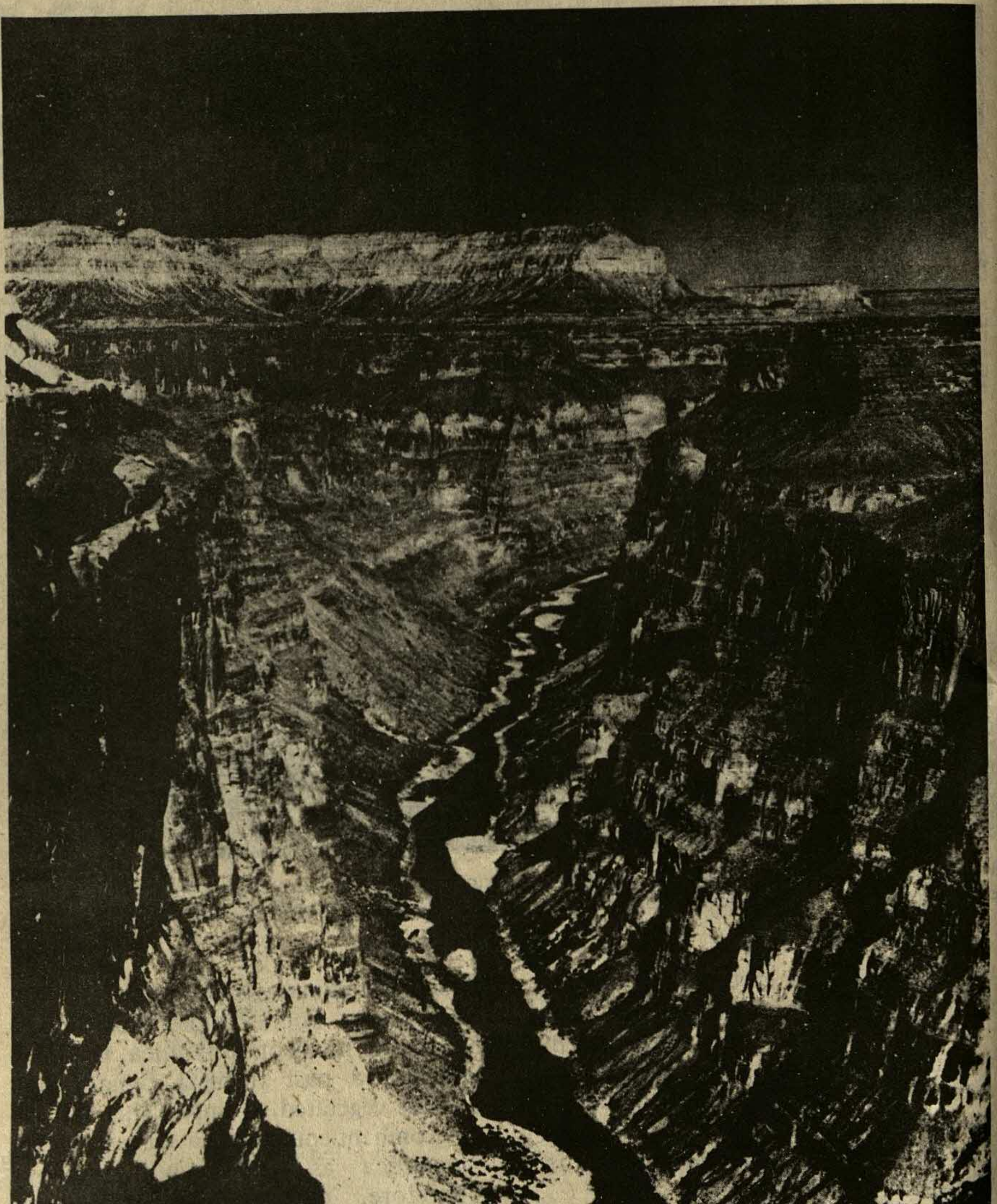


**Figure 12.3:** The Grand Canyon, Arizona, U.S.A. This canyon, which has been carved out by the Colorado River, is almost two kilometres deep. Notice the many beds of rocks exposed on the canyon walls. These beds are like the pages of a book. They tell us about the climate and the plants and animals that lived on the earth during the past 1000 million years. (Photo courtesy American Department of Information)

plants. These plants were the ones that the coal was formed from. Figure 12.4 is a photo of impressions of such plants.

Figure 12.5 is a dinosaur's footprint found preserved in a coal mine at Ipswich, Queensland. The footprint was formed when the giant reptile lumbered through swamps about 200 million years ago.

Such traces of past life are called fossils. Fossils can be the remains or casts of shells or bones, casts of whole organisms, imprints of leaves, footprints or tracks of animals or animal droppings.

Fossils usually occur in sedimentary rocks. If the rocks are changed by heat or pressure any fossils they contain may be destroyed. Rarely are fossils found in igneous or metamorphic rocks. Molten rock, from which igneous rocks form, destroys most traces of living things.

## Formation of fossils

A good fossil has the exact shape of the organism from which it formed. The material of the organism, however, is rarely preserved. It is often chemically altered, often dissolved out of the rock and sometimes replaced by new material.

The following are some of the ways in which fossilization may occur in sedimentary rocks.

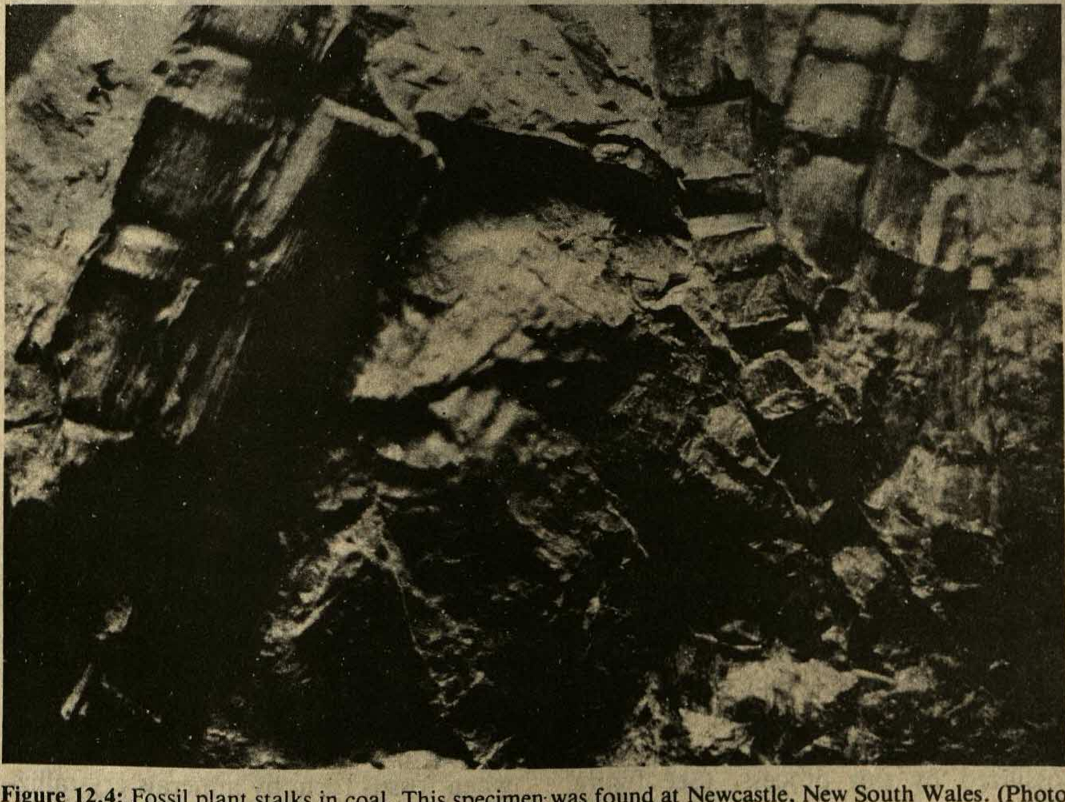


**Figure 12.4:** Fossil plant stalks in coal. This specimen was found at Newcastle, New South Wales. (Photo courtesy Australian Museum)

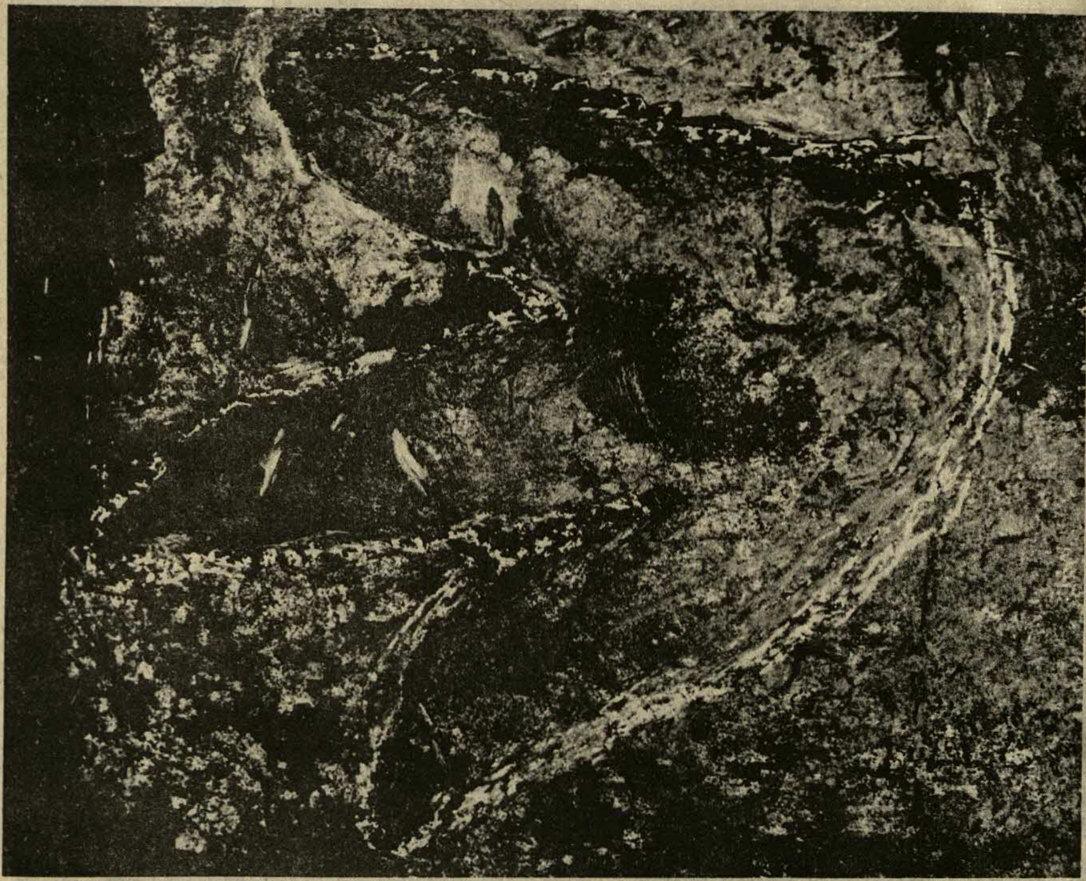


**Figure 12.5:** Fossil dinosaur footprint found in an Ipswich coal mine.

## Carbonation

Carbonation may occur when the remains of an organism are buried quickly so that little air is trapped. Conditions such as this could exist on the bed of a muddy lake.

During carbonation chemical changes occur. Gases are given off from the dead tissue leaving carbon behind. All that is left in the rock is a thin carbon film, which often shows the outline of the soft parts of the organism. Leaves are usually fossilized by this process. (See figure 12.4.)

## Cavities filled by crystallizing minerals

Many fossils are formed by minerals crystallizing in cavities. These cavities may be formed

- by the decay of the soft parts of an organism after it has died
- by the dissolving away of hard parts of a buried organism by groundwater.

The walls of a cavity in which a metal is cast are called the mould. Likewise, when fossils form by minerals crystallizing in a cavity, the walls of this cavity

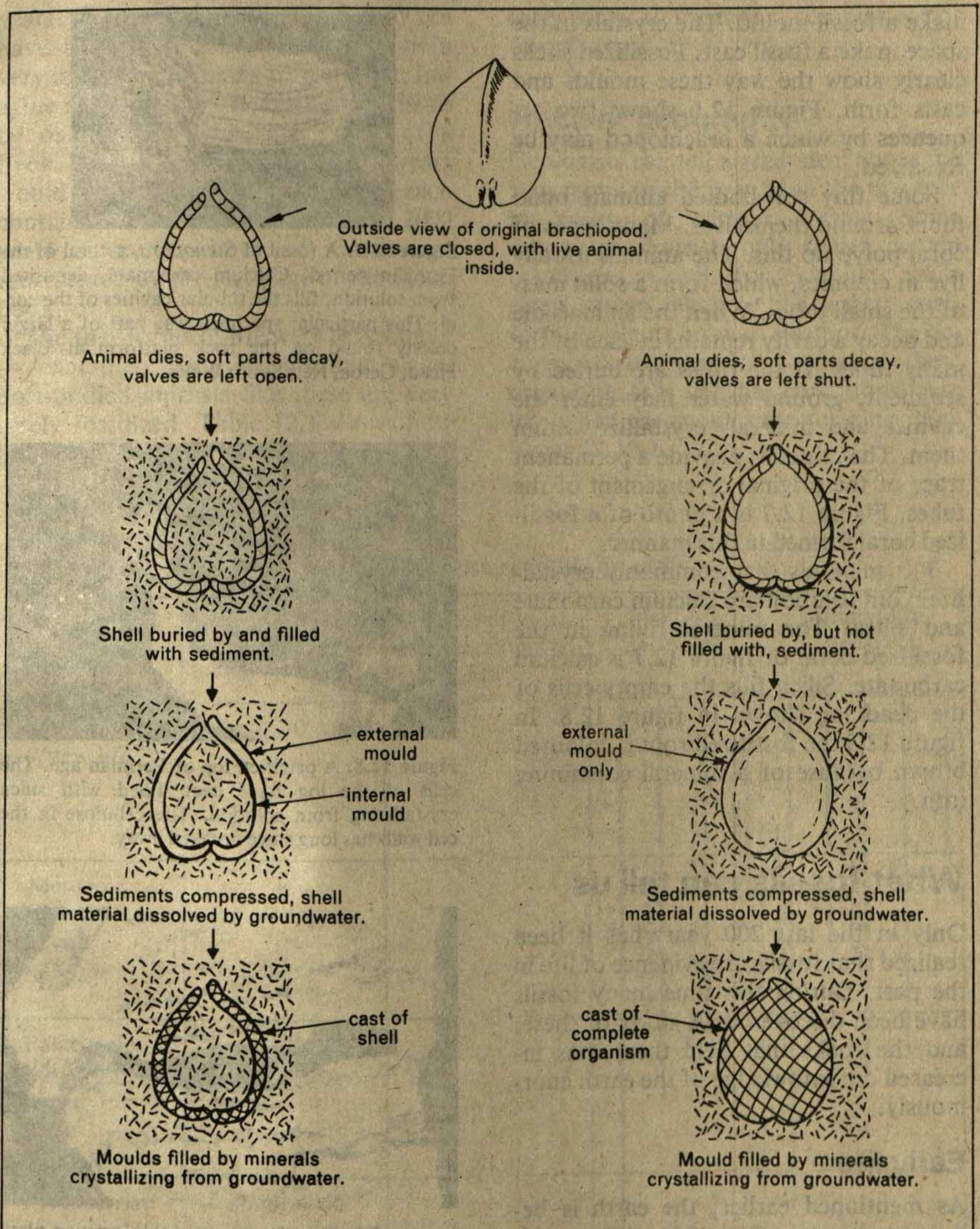

Outside view of original brachiopod. Valves are closed, with live animal inside.
Animal dies, soft parts decay, valves are left open.
Animal dies, soft parts decay, valves are left shut.
Shell buried by and filled with sediment.
Shell buried by, but not filled with, sediment.
external mould
internal mould
external mould only
Sediments compressed, shell material dissolved by groundwater.
Sediments compressed, shell material dissolved by groundwater.
cast of shell
cast of complete organism
Moulds filled by minerals crystallizing from groundwater.
Mould filled by minerals crystallizing from groundwater.

**Figure 12.6:** Possible ways in which a brachiopod can be fossilized. The top diagram is an outside view of a shell. The other diagrams are cross-sections. (Brachiopods are a kind of shellfish that are common and important fossils.)

make a fossil mould. The crystals in the space make a fossil cast. Fossilized shells clearly show the way these moulds and casts form. Figure 12.6 shows two sequences by which a brachiopod may be fossilized.

Some tiny soft-bodied animals build tubes around themselves. Many types of coral polyp do this. The animals usually live in colonies, which form a solid mass of the small tubes. When the animals die and decay a cavity remains in each of the many tubes. If the tubes are buried by sediment, ground water may enter the cavities and minerals crystallize within them. The minerals provide a permanent trace of the original arrangement of the tubes. Figure 12.7 is a photo of a fossilized coral formed in this manner.

The minerals that commonly crystallize from solution are calcium carbonate and silica. The mineral filling in the fossilized coral of figure 12.7 is calcium carbonate. Silica fills the empty cells of the dead log shown in figure 12.8. In figure 12.9 the fossilized root is coloured brown because of a mineral containing iron.

## What fossils can tell us

Only in the last 200 years has it been realized that fossils are evidence of life in the past. During this time many fossils have been discovered. A study of these, and the rocks that held them, has increased our knowledge of the earth enormously.

### Early life

As mentioned earlier, the earth is believed to be more than 4000 million years old. The oldest fossils are only 1000 million years old; therefore, life has existed on earth for at least 1000 million

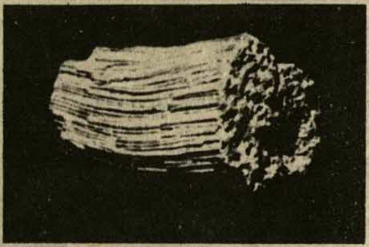


**Figure 12.7:** A fossil of *Stenopora*, a coral of the Permian period. Calcium carbonate, deposited from solution, fills the tubular cavities of the coral. This particular specimen was part of a larger colony found on the rock platform at Black Head, Geroa, New South Wales.

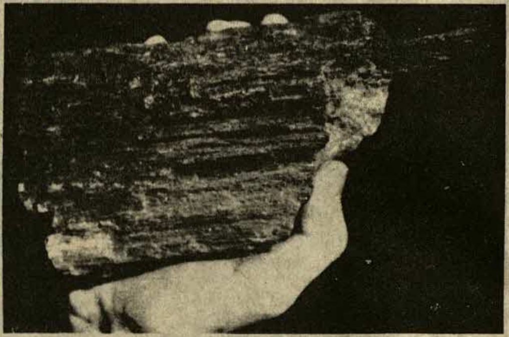


**Figure 12.8:** A petrified log of Permian age. The cells of the log have been filled with silica crystallizing from solution. The cellulose in the cell walls has long since decayed away.

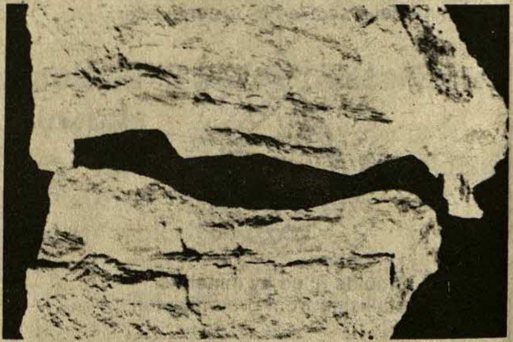


**Figure 12.9:** Fossilized root of the Permian plant *Glossopteris*. The root is called *Vertebraria*. This particular specimen is in a siltstone from Mulbring, near Cessnock, New South Wales. The rock is split through the middle of the fossil.

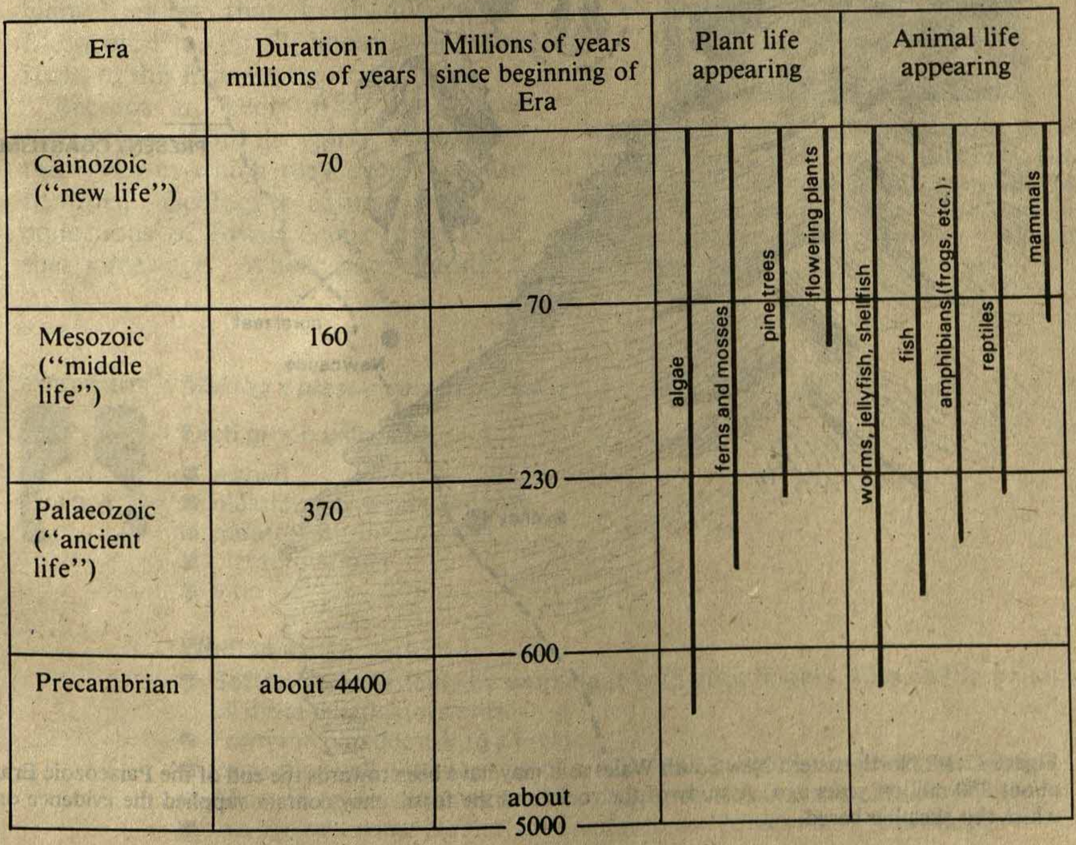
years. (The earliest forms of life may not have been fossilized.) This period is a very long time. To help to picture it, imagine the time since the birth of Christ to be represented by a single page of a book. On this scale, 1000 million years would be represented by 500 books each containing 1000 pages. The almost 2000 years since the birth of Christ are represented by the last page of the 500th book.

The first forms of life were very simple — examples being worms and algae. Soft-bodied animals like these are very rarely fossilized. Table 12.1 shows how living things have changed from these early forms to the many, complex forms found today.

## Ancient geography

Geologists can tell a great deal about the geography of the past from the presence in rocks of certain fossils. Some organisms flourish only under certain conditions. Coral, for example, needs clean, warm, shallow sea water; coal-forming plants grow in swamps. The occurrence in rocks of fossils of these organisms tells us what conditions were like when the rocks were forming. (See figure 12.10.)

**Table 12.1:** The history of life on earth



| Era | Duration in millions of years | Millions of years since beginning of Era | Plant life appearing | Animal life appearing |
|---|---|---|---|---|
| Cainozoic ("new life") | 70 | 70 | | |
| Mesozoic ("middle life") | 160 | 230 | flowering plants | mammals |
| Palaeozoic ("ancient life") | 370 | 600 | ferns and mosses<br>pine trees | fish<br>amphibians (frogs, etc.)<br>reptiles |
| Precambrian | about 4400 | about 5000 | algae | worms, jellyfish, shellfish |

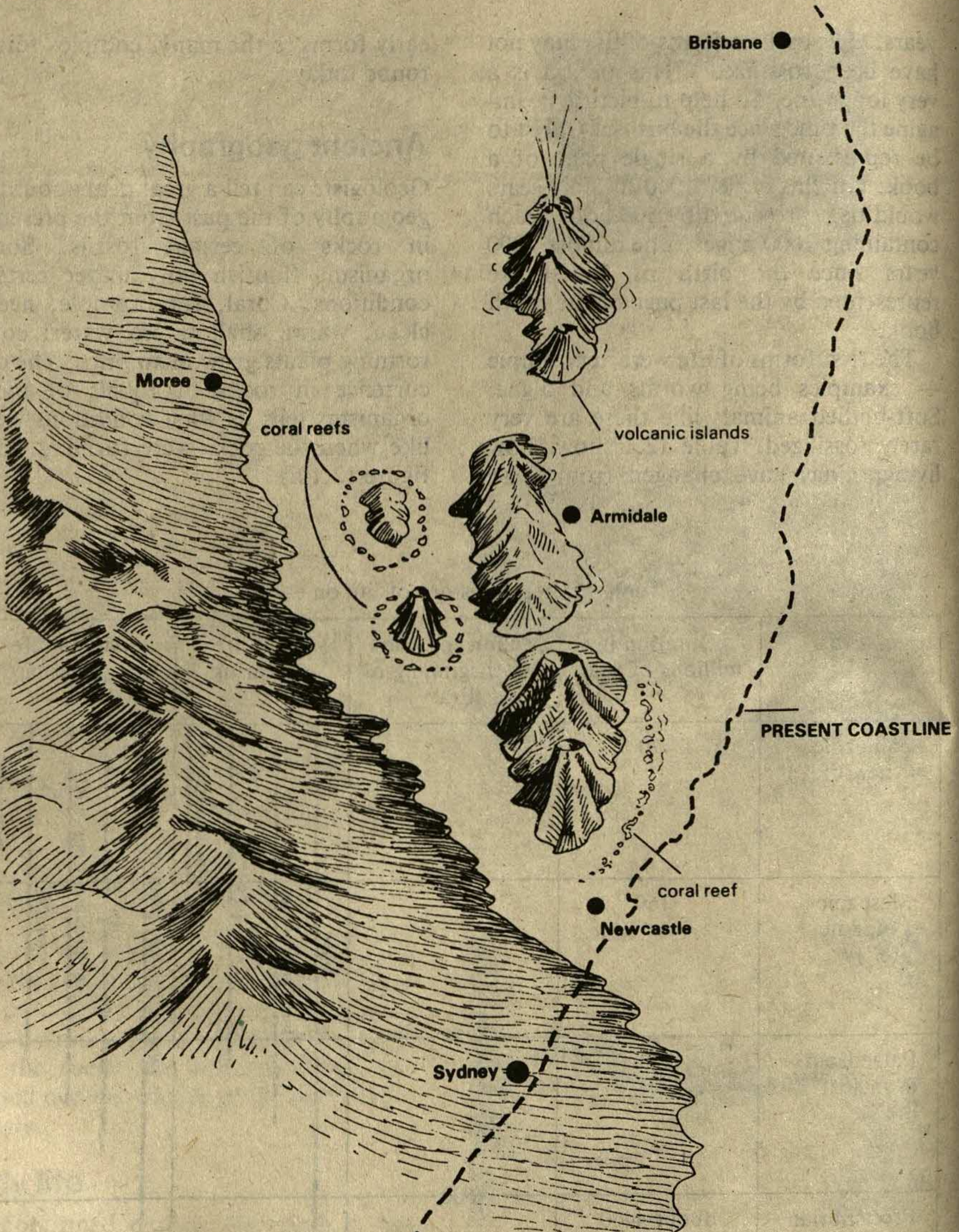


**Figure 12.10:** North-eastern New South Wales as it may have been towards the end of the Palaeozoic Era, about 350 million years ago. A study of the rocks and the fossils they contain supplied the evidence on which this sketch is based.

## The ages of rocks

The age of a rock is the time since it was formed. Geologists use various methods to estimate this time. Two of these were mentioned in the discussion of the age of the earth at the beginning of this chapter.

A third method is to use what are called *index fossils*. These are fossils of animals and plants that lived and flourished for a period of time and then became extinct. Rocks containing fossils of these organisms must have been laid down during this period of time. The fossils therefore indicate the age of the rock — hence the name index fossils. The plant *Glossopteris* is an indicator for the Permian Period of the Palaeozoic Era (see figure 12.11). Dinosaurs are giant reptiles that lived during the Mesozoic Era. Fossil dinosaurs indicate rocks of this Era (see figure 12.5).

Records are kept of all fossil types found throughout the world. The ages of the rocks in which they occur are also recorded. Geologists assume that like collections of fossils occur in rocks of the same age. When investigating a stratum of unknown age they closely examine any fossils in it. By comparing these fossils with the recorded fossil types they may be able to state the age of the stratum. (If a fossil is of an animal that did not change in millions of years, the age of the rock cannot be deduced very precisely.)

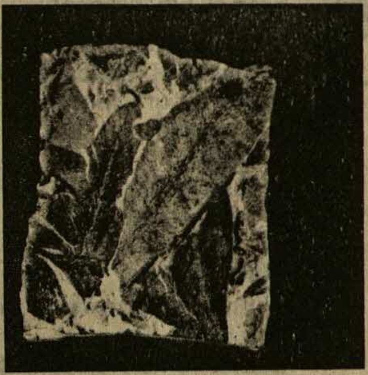


**Figure 12.11:** Fossil leaves of *Glossopteris*, one of the coal-forming plants of the Palaeozoic Era. Because it grew on the earth only during this Era, *Glossopteris* enables us to date beds of rocks in which its fossil is found. This is why it is called an index fossil.

**EXPERIMENT** *Making a plaster cast of a shell*

**12.1**

**Each group will need:**

- a shell
- plasticine or modelling clay
- paraffin oil
- plaster of Paris
- a tin

**What to do**

- Soften the plasticine by working it with your fingers. Add a little paraffin oil if the plasticine is stiff.
- Form the plasticine into a block.
- Paint the shell with paraffin oil and press it carefully into the plasticine.
- Allow the plasticine to stand for a few minutes and then lift out the shell.
- In a tin, mix some plaster with water to the consistency of porridge.

- Paint the plasticine with paraffin oil.
- Pour the plaster into the mould so that some flows over on to the top of the plasticine.
- Allow the plaster to set overnight, then remove it from the plasticine.

**Question**

**12.1** Describe what would have to happen for a fossil cast of a jellyfish to be formed.

**EXPERIMENT**

**12.2**

### *Making a model of a fossil leaf*

**Each group will need:**

- tin with lid
- dead leaf (choose a flat one)
- plaster of Paris
- Vaseline
- tongs
- Bunsen burner
- lacquer and brush

**What to do**

- Smear the inside of the lid with Vaseline and place the leaf in the lid. Press it down flat.
- Mix some plaster with water in the tin to make a thick paste. Pour it into the lid to a depth of about a centimetre.
- Allow the plaster to set overnight.
- Remove the plaster from the lid. Hold it with tongs in a Bunsen flame. Heat very gently by moving the plaster in and out of the flame. Stop heating when you have a good carbon impression of the leaf.
- Lacquer the model to preserve it.

**EXPERIMENT**

**12.3**

### *Making a model of fossil coral*

**Each group will need:**

- small piece of coral about 1 cm thick
- a tin
- tripod
- Bunsen burner
- paraffin wax
- hydrochloric acid
- paper cup
- scalpel
- tongs
- beaker
- Sellotape
- lacquer

**What to do**

- Moisten the coral with water and place it in the paper cup.
- Melt some paraffin wax in the tin and pour it over the coral in the paper cup.
- When the wax has solidified, remove the whole block of wax from the cup.

- Shave wax off one face of the block until the surface of the coral is exposed.
- Place the block of wax in a beaker with the shaved surface uppermost and cover it with hydrochloric acid. Leave overnight.
- Pour off the acid, wash the block and allow it to drain upside down.
- With the opening to the hole in the block uppermost, wrap Sellotape around the block to make a cup for the plaster.
- Mix the plaster and pour it into the Sellotape cup. Tap the cup to remove air bubbles.
- Allow the plaster to set overnight.
- Remove the Sellotape and place the block in a beaker of hot water to melt and remove the wax.
- Allow the cast to dry and then paint it with lacquer.

## Fossils

- Fossils are traces of past life found in rocks.
- Fossils may be formed by
  - minerals crystallizing in a mould
  - organisms changing into carbon under pressure.
- Fossils are useful because they give information about
  - the history of life on the earth
  - the past geography of the earth
  - the ages of rocks.
- The earth is thought to be between 4000 and 5000 million years old. Fossils indicate that life first appeared more than 1000 million years ago.

## Spelling list

Antarctica
Cainozoic
crystallize
dinosaur
fossilized
geologist
impression
Mesozoic
mould
occurrence
Palaeozoic
petrified
radioactive
silica

## Things to do

12.2 Examine a fossil of a *Glossopteris* leaf. (This is an index fossil.) Compare it with similarly shaped leaves of trees living today. Is there any difference?

12.3 Examine the skulls of some birds. Try to sketch the head of the bird using the skull as the only evidence.

**12.4** Obtain leaves of the Dawn Redwood, *Metasequoia*. The Dawn Redwood was only known by its fossils and therefore thought to be extinct until living specimens were discovered by a forester in China in 1945.

## More questions

**12.5** Outline ways in which fossils may form.
**12.6** Why are fossils very rarely found in igneous rocks?
**12.7** What minerals are commonly found in fossils?
**12.8** Why is a piece of fossilized wood heavier than the original wood?
**12.9** Refer to library books to find out about the history of the horse. Did you know that the ancestor of today's horses was little bigger than a dog? (R)
**12.10** What kinds of plants first appeared on earth? How long ago? (R)
**12.11** Long ago flying reptiles existed on earth. Look up library books to find pictures of these animals. Where were the fossils found? (R)

## Test yourself (chapter 12)

Write the answers to questions 1 to 3 in your workbook.

1. Name a rock that would show a geologist that there was once a swamp with dense vegetation in the area where the rock is found today.
2. Name the mineral most likely to be found in fossilized wood.
3. Name the Era in which dinosaurs existed.

In questions 4 to 9, choose the best answer and write its letter in your workbook.

4. It is unlikely that fossils would be found in
   (a) sandstone
   (b) granite
   (c) shale
   (d) limestone.
5. Which of the following animals would be the least likely to be fossilized?
   (a) humans
   (b) corals
   (c) earthworms
   (d) fish.
6. The presence of fossilized coral in rocks indicates the existence in the past of
   (a) freshwater lakes
   (b) warm shallow seas
   (c) tropical vegetation
   (d) freshwater swamps.

7. Marine fossils are most commonly found in
   (a) coal
   (b) basalt
   (c) limestone
   (d) granite.
8. An index fossil
   (a) is one that has been formed in the past
   (b) is one listed in the catalogue of fossils
   (c) can be used to tell the age of a rock
   (d) can be used to identify sedimentary rocks.
9. It is true to say of fossils that:
   (a) Fossils occur in all rocks laid down since the earth began.
   (b) There is a complete set of fossils of all animals that ever existed.
   (c) The older the rocks, the more complex are the fossils found in them.
   (d) Fossil reptiles occur in rocks older than those that contain the first mammals.

# 13

# Force

A force is a push or a pull. Sometimes a force can cause movement; the man exerts a force as he pushes his car towards the petrol pump in figure 13.1. At other times a force may not be big enough to cause movement; the girl in figure 13.2 realizes this as she tries to pull a stick out of the dog's mouth.

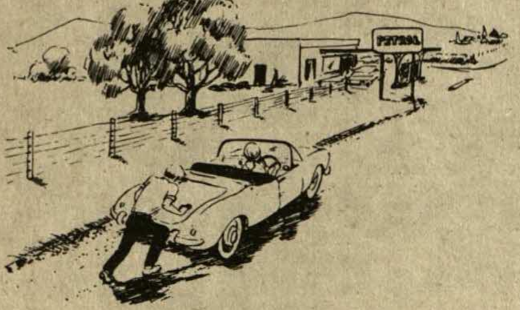


**Figure 13.1:** A force causing movement. To move the car along the road requires a continuous force against friction.

**Figure 13.2:** Forces that do not cause movement. The girl and the dog are pulling with equal forces in opposite directions.

Often we need to measure the size of a force. For example, when a locomotive is built, tests are carried out to measure its pull, or tractive effort. The diesel locomotive shown in figure 13.3 can exert a tractive effort of 31 000 kg force. The meaning of this statement is explained in figure 13.4. This method of measuring tractive effort would be cumbersome and so engineers have a simpler way of doing it. They couple the locomotive to a dynamometer car, which contains an instrument to measure the pull. This instrument gives them the same result as if they had tested the engine in the way shown in figure 13.4.

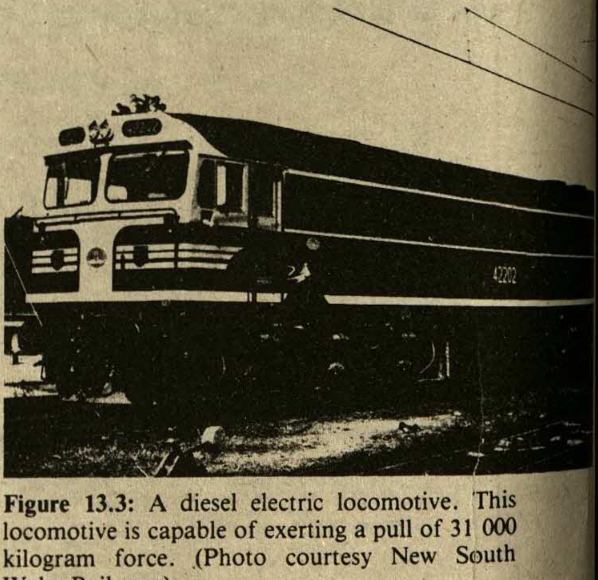


**Figure 13.3:** A diesel electric locomotive. This locomotive is capable of exerting a pull of 31 000 kilogram force. (Photo courtesy New South Wales Railways)

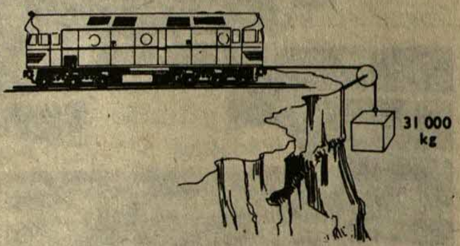


**Figure 13.4:** One way of measuring the tractive effort of a locomotive. The effort required to support the 31 000 kilogram may be given as 31 000 kilogram force.

## Measurement of force

When stating the size of any quantity we use units. The cost of an article is given in dollars; the dollar is a unit of money. The age of a person is given in years; the year is a unit of time. The size of a force may be stated in kilograms force. The kilogram force is a unit of force.

In the case of the locomotive in figure 13.4, gravity was used to measure the size of a force. Forces may also be measured by using a spring.

First we must find out how much the spring is stretched by forces of different sizes. To do this the spring is first hung on a nail, as in figure 13.5. A one-kilogram object is attached to the end and the stretch of the spring is measured on the scale. Additional kilogram objects are added, one at a time, and the additional stretch is measured in each case. It is found that the spring stretches the same amount for each extra kilogram added.

The spring can now be used to measure the size of another force. This is done by applying the force to it and noting how far the spring stretches.

## Inertia

All objects have inertia. People standing in a moving bus show the effect of their inertia when the bus stops quickly; they tend to continue moving forward down the aisle of the bus. Also because of inertia, car passengers in a head-on collision fly forward over the dashboard unless restrained by seatbelts. Passengers in a stationary car that is rammed from behind by another vehicle often suffer neck injuries. On impact the seat goes forward, carrying the passenger's body with it. The head, however, because of its inertia, tends to stay at rest. This causes the injury to the neck. All objects, if they are moving, tend to keep moving. Objects at rest tend to remain at rest.

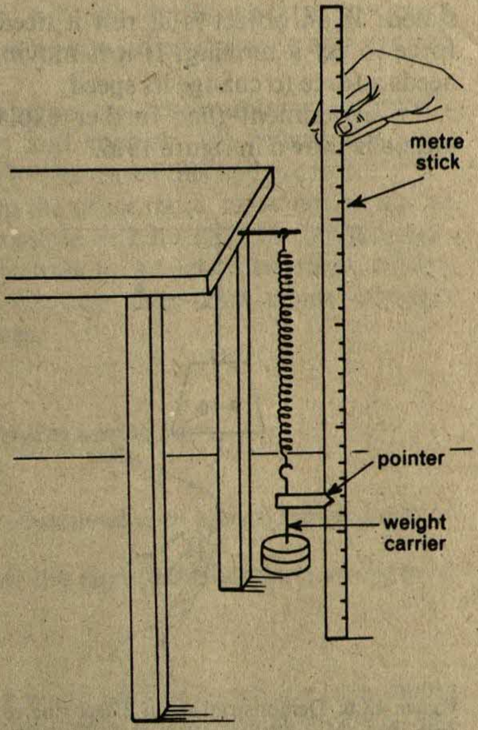


**Figure 13.5:** Calibrating a spring so that it can be used to measure the sizes of forces.

Sir Isaac Newton (1642–1727), one of the most brilliant scientists the world has known, was one of the first to have a clear understanding of inertia. He stated: If an object is at rest it needs a force to get it moving. If it is moving it needs a force to change its speed.

An experiment that further explains inertia is shown in figure 13.6.

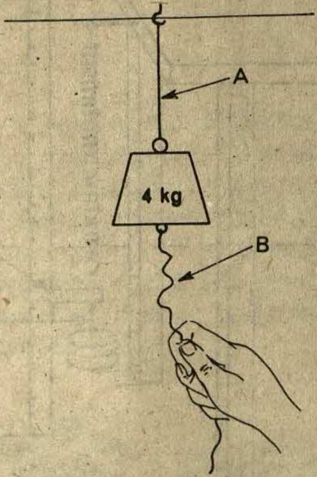


**Figure 13.6:** Demonstrating an effect due to inertia. Both A and B are pieces of the same kind of thread. A sharp tug downwards breaks thread B. Because of its inertia the 4 kilogram weight resists movement. By this resistance it shields thread A from the effect of the sudden tug on B.

Figure 13.7 shows another example of the effect of inertia. The boy feels very little of the blow from the hammer because of the inertia of the books.

A spacecraft travelling in space between the planets also illustrates the idea of inertia. Once the spacecraft is free of the earth's gravity, it travels onwards without change of speed. There is no need to use its motors, because there is no force acting on it. The motors are needed only to speed it up or to slow it down.

## Kinds of forces

*Gravity*. Every object is pulled to the earth by a force called gravity. This force is the weight of the object. The more material in an object the bigger is its weight. The force of gravity becomes less the further an object is from the earth. When an object is so far away that the force of gravity is negligible, the object is said to be outside the earth's gravitational field.

*Electrical forces*. A piece of perspex when rubbed with silk becomes charged with electricity. This electric charge exerts a force on any other charged object brought near it. This happens even in a vacuum; the charges exert a force on each other despite the fact that nothing joins them. As with gravity, the force between two electric charges becomes

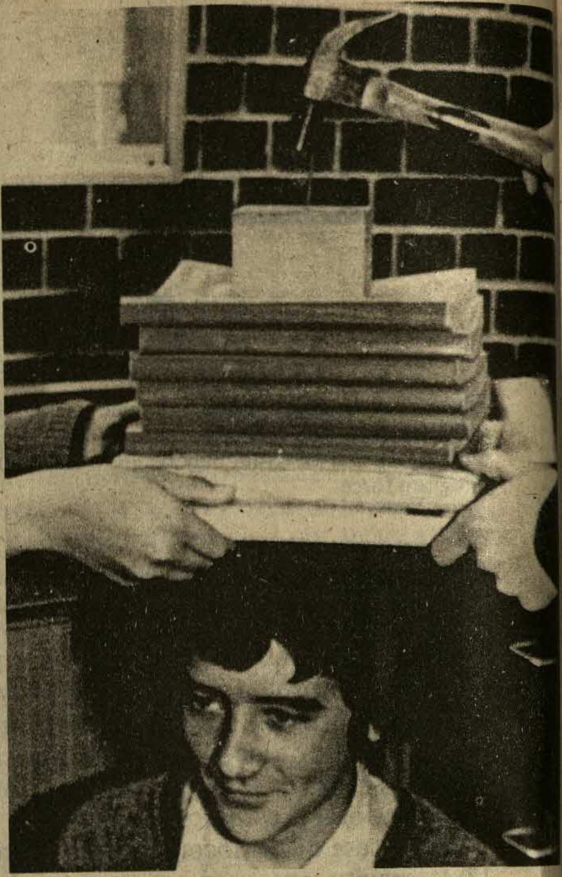


**Figure 13.7:** The boy feels very little of the blow of the hammer because of the inertia of the books. The books tend to resist the force of the blow and therefore very little force is transferred to the boy's head.

less as the distance between the charges increases.

***Friction — a passive force.*** Whenever we push a book across a table or a barrow along a path, the movement of these objects is opposed by forces due to friction. A car travelling along a road overcomes quite a lot of friction — friction in the gears and bearings, friction between the tyres and the road and friction due to air resistance. Friction is a passive force; it does not act until we try to move something and then it always acts against us.

Friction creates problems in machinery and engines. We reduce this friction by the use of oils and greases.

On the other hand, existence would be impossible without friction. Imagine trying to walk up a frictionless slope, or trying to stop cars and trains without brakes.

**EXPERIMENT 13.1**

### *Finding the breaking strength of a fine nylon fishing line*

**Each group will need:**

- length of very fine fishing line (one advertised with a breaking strength of about 2 kg would be suitable)
- spring balance able to record double the advertised breaking strength of the line

**What to do**

- Tie one end of the fishing line to a water pipe or bench leg (something fixed and steady). You will need to use double knots because nylon is very smooth and slips under tension.
- Tie the other end of the line to the spring balance.
- Pull on the balance, slowly increasing the tension until the line breaks.
- Record the reading when this happens.
- Test a number of pieces of line and tabulate your results.

**Question**

**13.1** What was the average breaking strength of the line? Was it a uniform line? In other words, was the breaking strength almost constant along its length?

**EXPERIMENT 13.2**

### *How hard can you push?*

**Each group will need:**

- set of bathroom scales

**What to do**

- Choose a situation where there is a grassy patch alongside a brick wall.
- Have two people hold the scales vertically against the wall.
- Ask each member of the group to push against the scales. (People should be barefooted when they push.) Record the maximum push that eacn person can steadily exert for 5 seconds.
- Weigh each member of the group.
- Tabulate the group's results.

**Question**

**13.2** Is there any correlation between the weight of the person and the size of the push he or she could exert? In other words, can you say "the heavier the person, the stronger the push"?

**EXPERIMENT 13.3**

*Studying the force of sliding friction*

**Each group will need:**

- a number of pieces of wood of different sizes from the same plank
- cup hooks to be screwed into each piece of wood
- various 100 g weights and a 1 kg weight
- spring balance to read to 1 or 2 kg

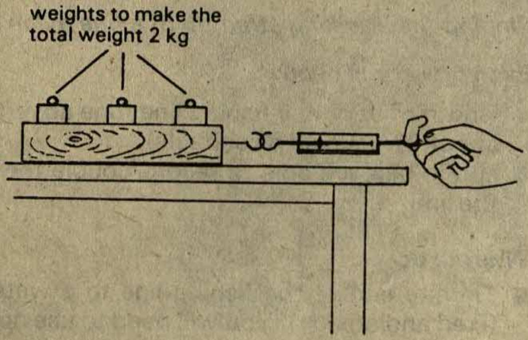


**Figure 13.8:** Measuring the force required to just move the block over the surface of the table.

**What to do**

- Weigh each piece of wood and write the weight on the wood.
- Place one piece on the bench. Add weights to make a total of 2 kg (including the weight of the wood).
- Attach the spring balance (see figure 13.8) and measure the pull needed to just move the block along the bench.
- Record your result. Repeat the experiment with a block of different base area. Make sure the total weight is 2 kg.
- Tabulate your results.

| Total weight on bench | Force required to just move block |
|---|---|
| 2 kg | |

**Question**

**13.3** What did you find out? Did you need a greater pull for a greater area or was it approximately the same for all surface areas?

## Force

- A force is a push or a pull.
- Forces may be measured in kilograms force. The kilogram force is called a unit of force.
- If an object is at rest it needs a force to get it moving. If it is moving it needs a force to change its speed.
- Some common forces are those due to gravity, electric charges and friction.
- Friction always opposes movement.

## Spelling list

collision
diesel
engineer
friction
gravitational
inertia
kilogram
resistance
stationary

## Things to do

13.4 Place a cup of water on a sheet of paper on a bench. Can you remove the paper without touching the cup and without spilling any water? Explain how this can be done successfully.

13.5 Tie a length of thread to the leg of a chair. Try to move the chair across the floor by pulling on the thread. How would you do it?

13.6 Puncture a tennis ball with a hot nail. Fill the tennis ball with water. Do this by squeezing out all the air and allowing the ball to expand under water. Spin the ball on a bench. Stop it from spinning by pressing on it with your finger. What happens when you lift your finger off the ball? Why?

## More questions

13.7 As the car moves steadily towards the petrol station in figure 13.1, what force or forces is the man pushing against?

13.8 A man nailing palings to a light fence finds it helpful to have a person on the other side holding a brick against the rail. Why?

13.9 How do seat belts help to reduce injuries in car collisions?

13.10 Why are straps or hand rails necessary in buses?

13.11 Why do objects weigh less on the moon than on earth?

13.12 Give three cases where friction is a disadvantage and three cases where it is a help.

**13.13** Why is it necessary to use rockets to change the direction of a space ship? Why not use rudders?

**13.14** How is it that a locomotive that has a tractive effort of 31 000 kg force can haul a train weighing 100 000 kg?

## Test yourself (chapter 13)

Write the answers to questions 1 and 2 in your workbook.

1. State a unit used for measuring forces.
2. State two common forces acting everywhere around us.

In answering questions 3 to 5, choose the best answer and write its letter in your workbook.

3. A spring, suspended from a nail, is stretched 5 cm when a weight of 2 kg is attached. The same spring when loaded with 3 kg would stretch
   (a) 6 cm
   (b) 7.5 cm
   (c) 10 cm
   (d) 15 cm.
4. Supports are used on the backs of car seats to
   (a) act as a head rest, particularly on long journeys
   (b) protect the head in the event of a collision at the front
   (c) protect the head in the event of a collision at the rear
   (d) protect the neck in the event of a collision at the rear.
5. A space ship is travelling in space well away from the earth's gravity. It needs to change direction to the right. This can be done by
   (a) firing a rear rocket that points to the right
   (b) firing a rear rocket that points to the left
   (c) by turning a rear rudder to the right
   (d) by turning a rear rudder to the left.

# 14

# Mass and density

## Mass

In chapter 13 we explained inertia. In this chapter we ask the question: what does the inertia of an object depend on?

Imagine ourselves inside a spaceship that is travelling to another planet. We are several million kilometres away from the earth and therefore gravity is practically zero. Objects in the spaceship, and the spaceship itself, are weightless.

Suppose an argument breaks out between two members of our crew. One takes hold of a spanner and hurls it at the other. But the spanner is weightless. Will it hurt the other crew member when it strikes him? The answer is yes — it hurts him as much as if it were thrown across a room on earth. This is because the spanner has the same inertia in the spaceship as it would have on earth.

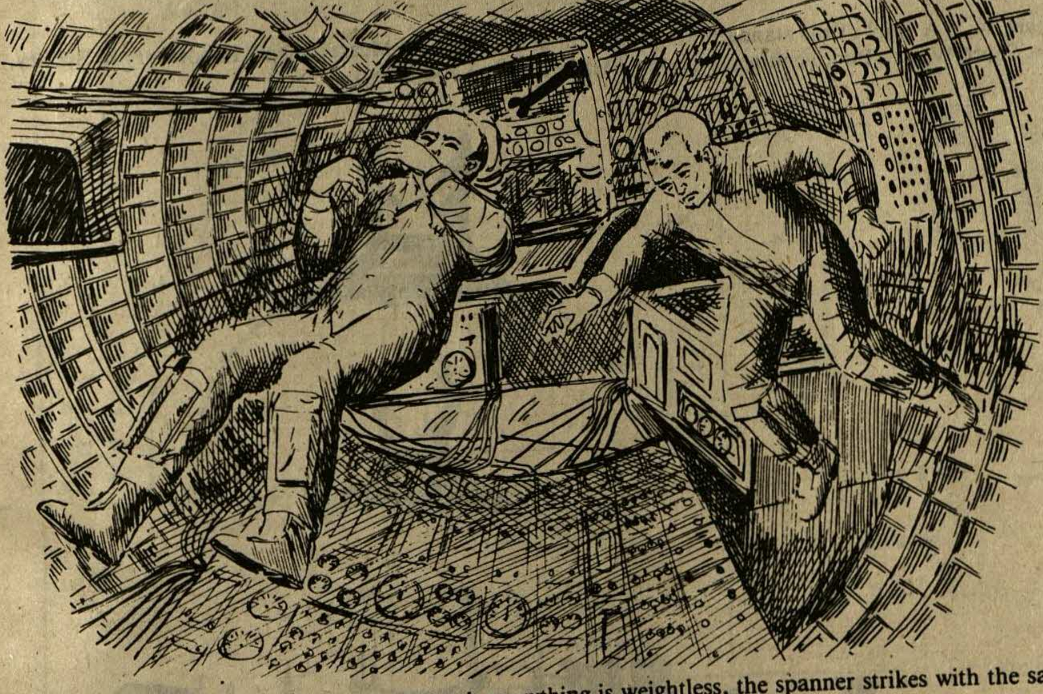


**Figure 14.1:** An argument in space. Although everything is weightless, the spanner strikes with the same force as it would if thrown across a room on earth.

From this incident we see that inertia does not depend on the weight of an object, it depends on the quantity of material in it. This quantity of material is called its mass. The mass of an object is the same whether gravity is acting on it or not. For example, the food in the spaceship is weightless but its mass does not alter. For this reason its value as food would be the same no matter where the spaceship was.

## Standards of mass

The person who buys a kilogram of chops for the family meal expects a certain mass of meat. The butcher measures this mass by weighing it — the more mass the greater the weight. The butcher's scales are checked periodically to see that they register one kilogram when a mass of one kilogram is placed on them.

In Paris there is a lump of platinum alloy that was declared the standard kilogram in 1889. This lump of alloy should be placed on the butcher's scales when they are tested for correctness. But it is impossible to use a single lump of alloy to test all the scales in the world; therefore copies of the standard kilogram have been made and distributed to the various countries that need them.

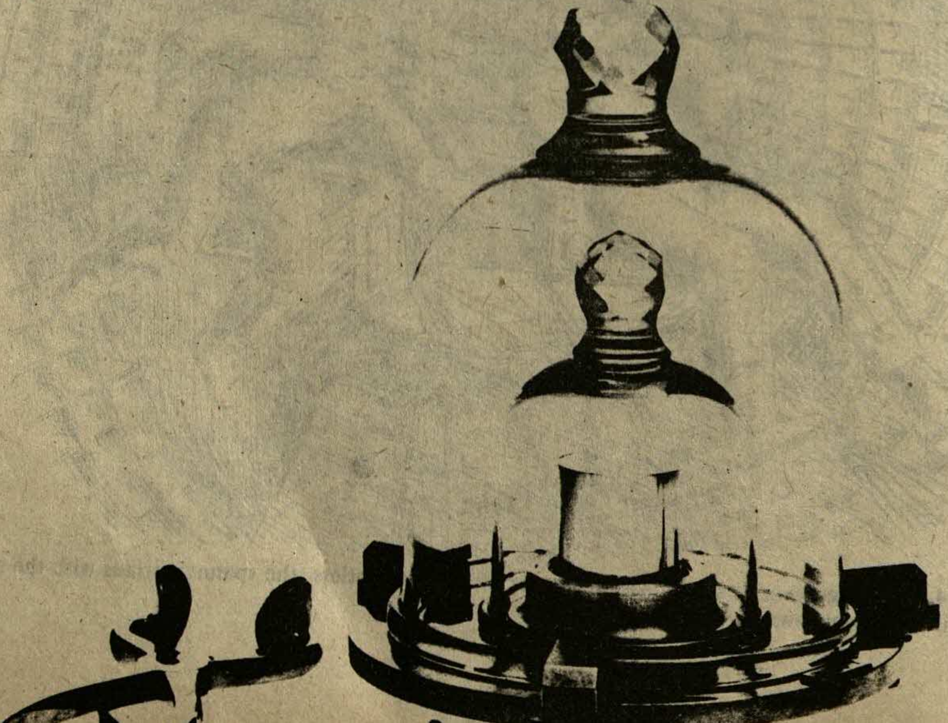
Scientists often use one-thousandth of the kilogram as a unit of mass. This is the gram (g).

1000 grams = 1 kilogram (kg)

## Density

The spanner that was hurled across the spaceship hurt the man not only because it had a lot of mass, but also because its mass was packed into a small space. The

**Figure 14.2:** A copy of the standard kilogram kept at the National Measurements Laboratory in Sydney, New South Wales. (Photo courtesy National Measurements Laboratory)



spanner was made of steel and steel is a dense substance. It is denser than wood or aluminium but not as dense as lead.

The density of a substance depends on its mass and the space or volume into which the mass is packed. Lead is dense because there is a lot of mass in a small volume. Cork, on the other hand, has a low density because there is a small mass in a large volume.

## Measuring density

The density of a substance is the mass of the substance in a particular volume of it. For example, the density of lead is 11 400 kilograms per cubic metre ($kg/m^3$) and the density of water is 1000 $kg/m^3$.

Table 14.1 lists the densities of some common substances. Figure 14.3 shows ways of calculating the densities of some of these substances.

**Table 14.1:** Densities

| Substance | Density in kilograms per cubic metre |
|---|---|
| gold | 19 000 |
| uranium | 18 500 |
| lead | 11 400 |
| copper | 8 900 |
| iron | 7 900 |
| rock | 2 600 (average) |
| aluminium | 2 700 |
| magnesium | 1 700 |
| water | 1 000 |
| human body | 1 000 (average) |
| petrol | 750 |
| cork | 250 |

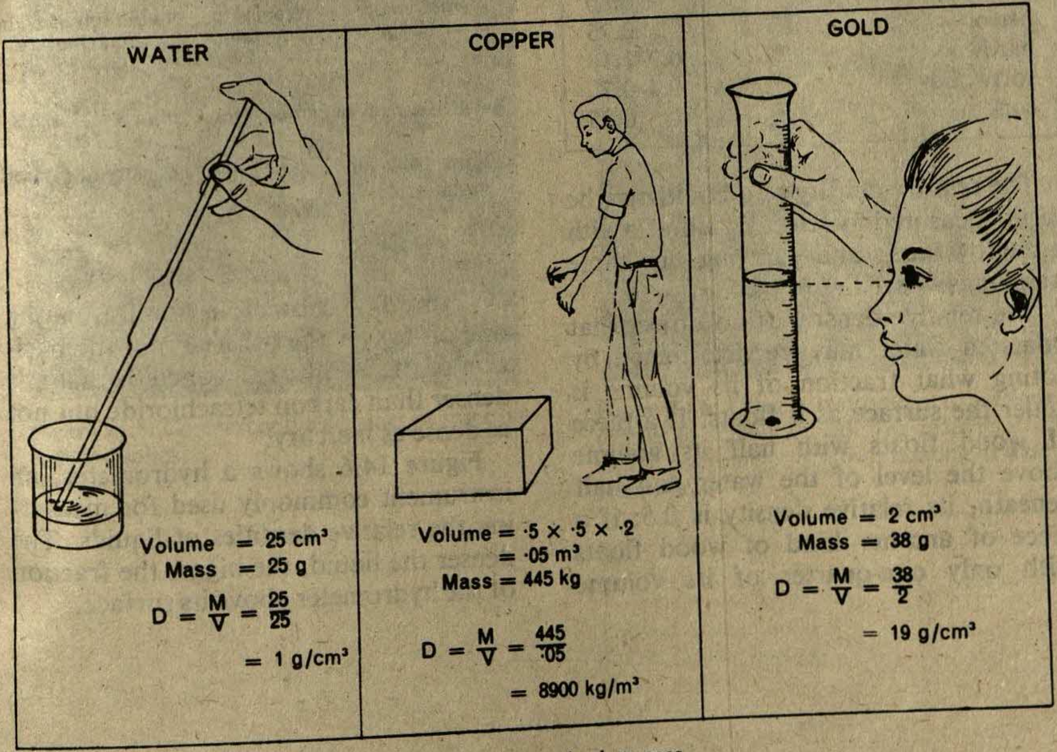


**Figure 14.3:** Different methods of finding the densities of substances.

## Relative density

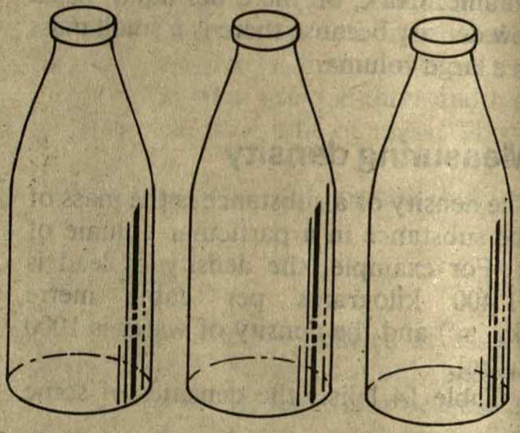
When seeking information about the density of a substance we usually wish merely to compare it with some other substance. Table 14.2 lists the densities of a number of substances compared with the density of water. These are called relative densities.

**Table 14.2:** Relative densities (water = 1)

| | |
|---|---|
| gold | 19.0 |
| mercury | 13.6 |
| lead | 11.4 |
| iron | 7.9 |
| various rocks | 2.4–3.0 |
| aluminium | 2.7 |
| sea water | 1.03 |
| milk | 1.03 |
| water | 1.00 |
| ice | 0.92 |
| human body | 0.9–1.1 |
| kerosene | 0.80 |
| petrol | 0.75 |
| hardwoods | 0.7–1.1 |
| softwoods | 0.4–0.7 |
| cork | 0.25 |

The relative density of a liquid may be easily measured by selecting a bottle with a narrow neck and carrying out three weighings — see figure 14.4.

The relative density of an object that floats in water may be determined by noting what fraction of its volume is under the surface as it floats. If a piece of wood floats with half its volume above the level of the water and half beneath, its relative density is 0.5; if a piece of another kind of wood floats with only one-quarter of its volume showing and three-quarters of it beneath the surface, its relative density is 0.75. An iceberg floats with only about one-tenth of its volume showing above the surface. We can therefore conclude that the relative density of ice is about 0.9.


Weight empty = 0·2 kg
Weight full of water = 1·2 kg
Weight full of carbon tetrachloride = 1·5 kg

Relative density of carbon tetrachloride $= \frac{1.3}{1} = 1.3$

**Figure 14.4:** Finding the relative density of carbon tetrachloride.

Figure 14.5 shows four liquids floating one on top of the other. From the position of the iron we can conclude that it is denser than carbon tetrachloride but not as dense as mercury.

Figure 14.6 shows a hydrometer, an instrument commonly used for measuring the relative densities of liquids. The denser the liquid, the bigger the fraction of the hydrometer above its surface.

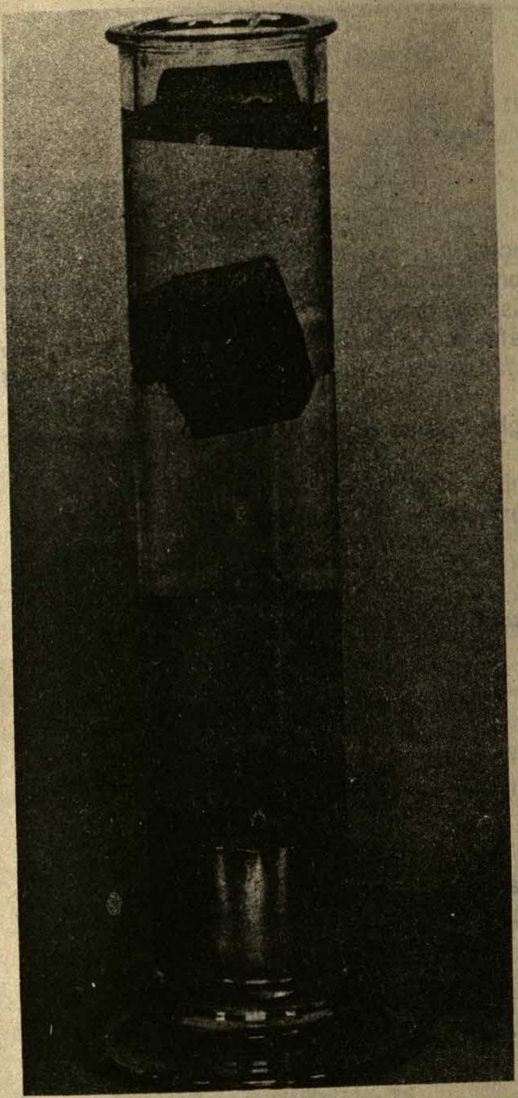


**Figure 14.5:** Comparing the densities of some liquids and solids.

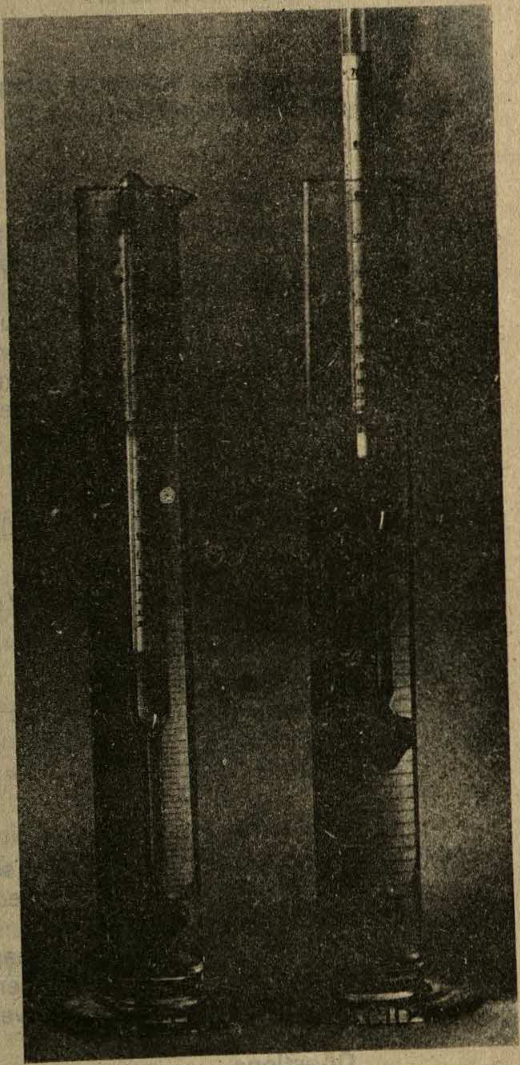


**Figure 14.6:** Using a hydrometer to measure the density of sulphuric acid. The reading is 1.8. A similar hydrometer is shown floating in water for comparison.

EXPERIMENT 14.1

*How dense is water?*

**Each group will need:**

- two small beakers (100 mL)
- 25 mL pipette
- balance

**What to do**

- Weigh one beaker on the balance.
- Pour some water into the second beaker. Suck up water from this beaker into the pipette, until the level is well above the mark on the stem.
- Place the first joint of your forefinger over the top of the stem, as in figure 14.3. Allow the water level to fall until the bottom of the meniscus is level with the mark on the stem.
- Empty the pipette into the weighed beaker. Do not blow down the pipette, just let the water run out.
- Weigh the beaker and the 25 mL of water.
- Calculate the density of water in grams per cubic centimetre ($g/cm^3$). (Note that $1\ mL = 1\ cm^3$.)

EXPERIMENT 14.2

*Which is heavier — a load of wet sand or a load of dry sand?*

**Each group will need:**

- dry sand
- beaker (100 mL)
- balance
- spatula

**What to do**

- Fill the beaker with dry sand and level the surface by drawing a ruler across it. Weigh the beaker full of sand.
- Empty out the sand.
- Wet some sand on newspaper.
- Add wet sand to the beaker with a spatula. Level off as before.
- Weigh the beaker full of wet sand on the balance.

**Questions**

**14.1** Which is the heavier — dry sand or wet sand?

**14.2** How do you account for your result? Remember that sand is about 2.5 times as dense as water.

## Spelling list

aluminium
density
hydrometer
meniscus
pipette
relative
tetrachloride

## Mass and density

- The mass of an object is the quantity of material in it.
- The density of a substance is the mass of a unit volume of the substance.

$$D = \frac{M}{V}$$

- Density may be measured in kg/m$^3$ or g/cm$^3$.
- The relative density of a substance is its density compared with the density of water at the same temperature.

## Things to do

**14.3** Half fill a cup with water. Add ice cubes until the water is on the point of overflowing. What happens to the water level as the ice melts? How do you account for the result?

**14.4** Make your own hydrometer by tying a piece of lead foil on to the end of a pine stick about 15 cm long. Place the stick in water (lead down) and mark the water level on its side. Use your hydrometer to compare densities of methylated spirits, kerosene and salt water.

**14.5** Have a competition. Wrap a glass marble in sheet lead to disguise what is inside. Do the same with a piece of wood and another sheet of lead. Do not make the "parcels" the same size. How can you distinguish between the parcels without unwrapping them?

**14.6** Imagine you give a goldsmith 50 g of pure gold with which to make a ring. You receive the ring. It weighs 50 g but it does not appear to be the same colour as the original gold. You suspect some of the gold has been replaced by a cheap metal. How can you find out without destroying the ring?

## More questions

**14.7** Which is the denser, honey or water? How do you know?

**14.8** Gases are much less dense than either liquids or solids. What is an explanation for this?

**14.9** What is the effect of change of temperature on the density of a substance?

**14.10** How does an increase in pressure affect the density of (a) solids, (b) liquids, (c) gases?

**14.11** A bottle weighs 0.5 kg empty. Full of water it weighs 2 kg and full of oil, 1.5 kg. What is the relative density of the oil?

**14.12** Which has the greater weight — a kilogram of cork or a kilogram of lead? Which would have the greater volume?

**14.13** Arrange the following in the order of their weights, naming the lightest first: a gold ring, a litre of milk and a half-litre aluminium saucepan. Which has the greatest volume of material in it and which has the greatest density?

**14.14** A steel plate of mass 2 kg is taken from the earth to the moon. Discuss the changes, if any, that take place in the mass, weight, volume and density of the plate during the journey.

**14.15** Find out exactly how a submarine dives and surfaces. (R)

## Test yourself (chapter 14)

Write the answers to questions 1 to 3 in your workbook.

1. A bag of sawdust weighing 1 kg and a block of lead weighing 100 g are placed in front of you.
   (a) Which is the heavier?
   (b) Which is the denser?
   (c) Which occupies the greater volume?
2. Refer to figure 14.5.
   (a) Which is the densest solid?
   (b) Which is the lightest (least dense) liquid?
3. A piece of metal weighs 40 g. Some water is poured into a measuring cylinder. The volume reads 53 cm$^3$. The piece of metal is allowed to slide into the cylinder. The volume now reads 58 cm$^3$. What is the density of the metal?

In answering questions 4 and 5, choose the best answer and write its letter in your workbook.

4. During a game of tennis the ball is struck by the racket. At the moment of impact the air inside the ball
   (a) becomes heavier
   (b) becomes lighter
   (c) becomes denser
   (d) undergoes no change whatsoever.
5. The air in a motor-car tyre after a long run on a hot day
   (a) becomes heavier
   (b) becomes lighter
   (c) becomes denser
   (d) undergoes none of the above changes.

# 15

# Pressure

Chapter 13 was about force; this chapter is about pressure. Although people sometimes use these two words as though they meant the same thing, force and pressure are two different concepts.

Look at figure 15.1. This semitrailer is carrying a huge load; the force on the road is quite large. But the semitrailer has 46 wheels. Each wheel supports only $\frac{1}{46}$th of the load, making the tyre pressure on the road quite small.

Snowshoes and skis provide other examples of the same principle. A heavy man can slide easily over soft snow on a pair of skis while a child without skis will sink to its knees in the same place. The man obviously exerts the greater force down on the snow but, because the force is spread over a much greater area (the area of a ski is much larger than the area of the sole of a shoe), the pressure is considerably less. In fact, the force down on each square centimetre of snow under the ski is only $\frac{1}{40}$th of a kilogram while the force down on each square centimetre of snow under the child's shoe is $\frac{1}{8}$ of a kilogram — five times as great. See table 15.1.

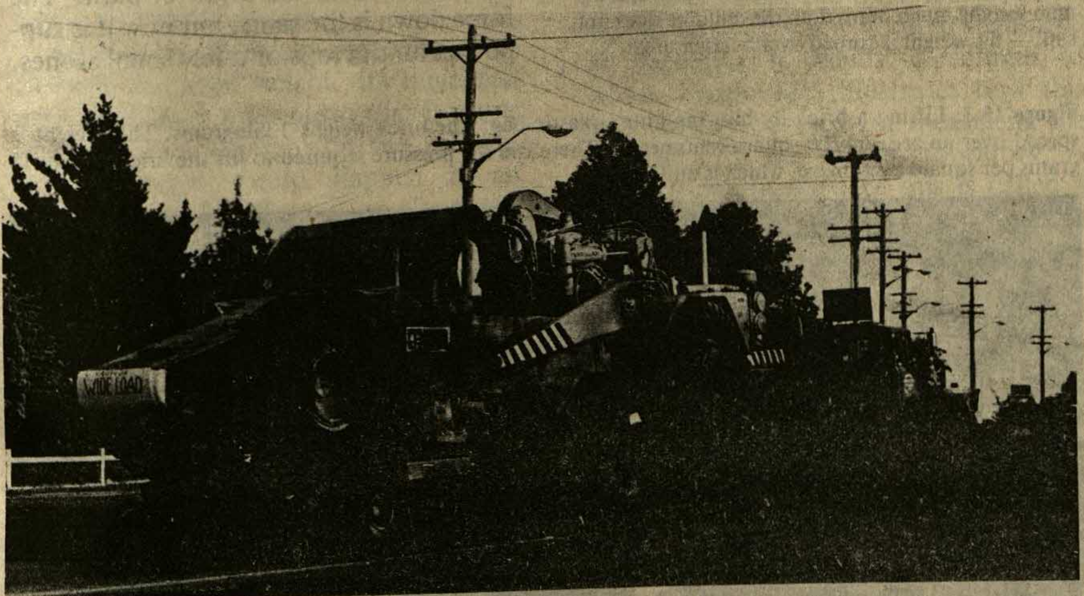


**Figure 15.1:** A semitrailer with 46 wheels. Because the load is distributed over all the wheels, each one carries only about $\frac{1}{46}$th of the load. This means only a relatively low pressure of air is needed in the tyres.

**Table 15.1:** Comparing pressures

| | MAN | CHILD |
|---|---|---|
| Weight | 75 kg | 25 kg |
| Area on snow | two skis = 3000 cm² | two shoes = 200 cm² |
| Pressure exerted on snow | $\frac{\text{weight}}{\text{area}} = \frac{75}{3000}$<br>$= \frac{1}{40}$ kg/cm² | $\frac{\text{weight}}{\text{area}} = \frac{25}{200}$<br>$= \frac{1}{8}$ kg/cm² |

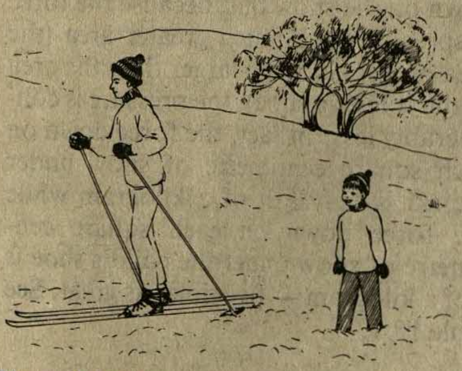
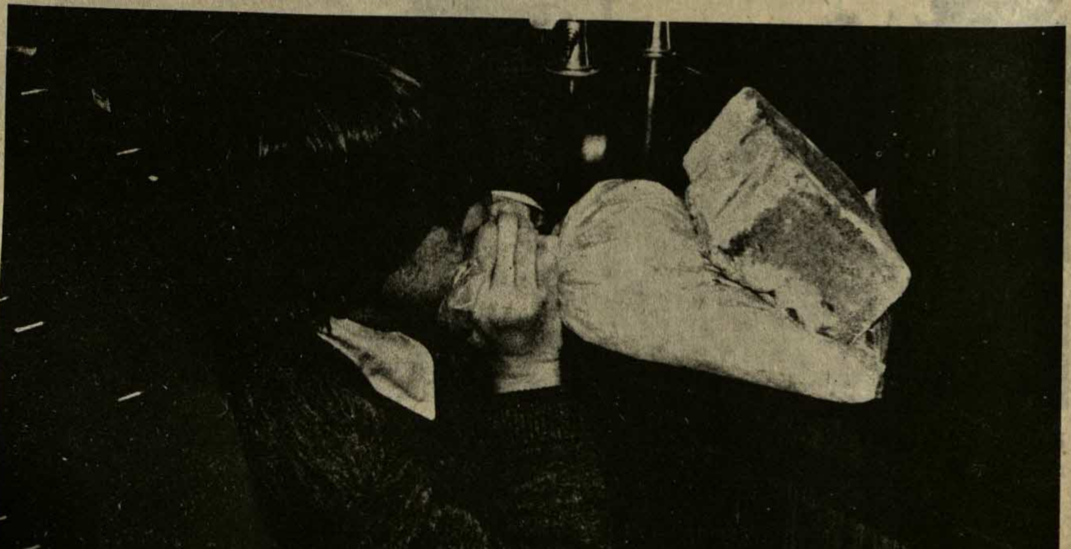


**Figure 15.2:** Moving over soft snow. Although the man weighs much more than the child he does not sink — his weight is spread over a larger area.

Figure 15.3 shows how a brick may be lifted by blowing into a plastic bag. It seems strange that you can support a house brick on air in a plastic bag. But remember, it is a case of reducing the pressure. The greater the area of the bag supporting the brick the smaller the force down on each square centimetre of it.

You can comfortably walk barefooted on a lawn. But what happens when you walk barefooted on a gravel path? The force down is the same, but now it is supported on the tops of a few small stones.

**Figure 15.3:** Lifting a brick by blowing into a plastic bag. The brick weighs 3 kilograms. This weight is spread over an area of 200 square centimetres. Therefore the pressure required to lift the brick is only 15 grams per square centimetre, which is quite small.



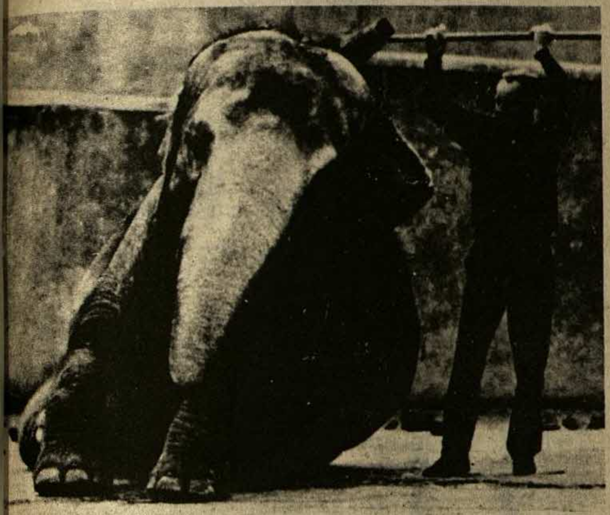


**Figure 15.4:** Elephants' feet are very wide and therefore cover a big area. This results in a relatively small pressure. A woman walking across a lawn in high-heeled shoes would leave a deeper impression than an elephant.

The area is therefore very much smaller, so the pressure the stones exert on your feet is very much greater.

An elephant has feet well adapted to carrying its huge weight. Its huge feet with their large soles mean that it exerts relatively low pressure on the ground. Imagine what would happen if an elephant had feet like an antelope and walked into some soft ground.

## Units used for measuring pressure

We have been using the kilogram per square centimetre as a unit of pressure. This is usually given as kilogram force per square centimetre, or kgf/cm$^2$. Other units are:

- kilogram force per square metre (kgf/m$^2$)
- gram force per square centimetre (gf/cm$^2$).

The kilopascal (kPa) is another unit of pressure.

$$10 \text{ kPa} = 1 \text{ kgf/m}^2$$

## Formula for calculating pressure

From the examples given we can see that

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

$$P = \frac{F}{A}.$$

This formula shows that, on the same area, doubling the force would create double the pressure. Doubling the area, with the same force, would halve the pressure.

## Measuring the pressure of gases

As well as using the units listed above, the pressure of a gas is often measured by balancing it against a column of liquid. Figure 15.5 illustrates how this method may be used for measuring the pressure of a gas in the laboratory. A piece of equipment like this is called a manometer. The greater the gas pressure, the higher the water level rises in the right-hand arm.

Figure 15.6 shows how a manometer may be used to test the maximum pressure a person can exert when the chest muscles act on the lungs. Water would be too light for this test, so mercury is used instead. The boy is pushing the mercury up to a height of 12 cm in the left-hand arm. Mercury is 13.6 times as dense as water. Therefore 12 cm of mercury is equivalent to 163.2 cm (12 × 13.6 cm) of water.

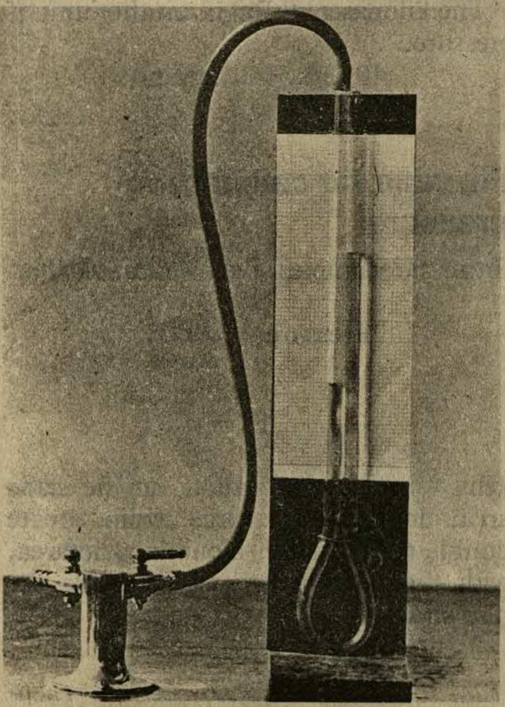


**Figure 15.5:** Measuring the pressure of the gas in the laboratory. The pressure in the pipes must be greater than air pressure, otherwise the gas will not flow out when the tap is turned on. In this figure the pressure of the gas exceeds air pressure by 7.5 centimetres of water.

The atmosphere at sea level can support a column of mercury of average height 76 cm. Using this fact, let us calculate the pressure of the atmosphere in $\text{kgf/cm}^2$. Imagine a column of mercury 76 cm high resting on a base of one square centimetre. This would be equivalent to 76 cubic centimetres of mercury one on top of the other. Each cubic centimetre of mercury weighs 13.6 grams. Therefore the pressure of this column on the base would be:

$$\begin{aligned} & 76 \times 13.6\ \text{gf/cm}^2 \\ = {} & 1033.6\ \text{gf/cm}^2 \\ = {} & 1.0336\ \text{kgf/cm}^2 \\ = {} & \text{approximately } 1\ \text{kgf/cm}^2 \end{aligned}$$

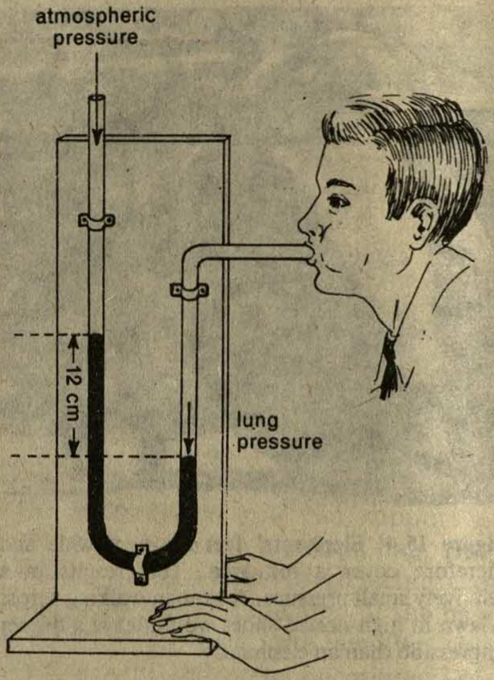


**Figure 15.6:** Testing lung pressure. In this diagram the person is exerting a pressure greater than atmospheric pressure by 12 centimetres of mercury.

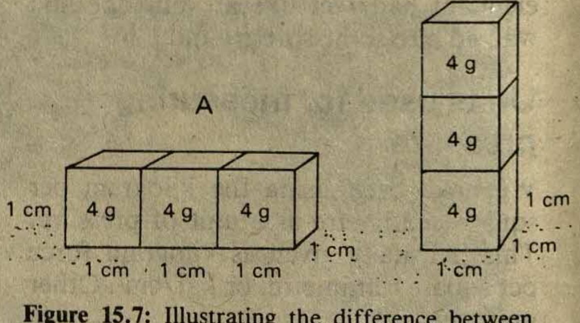


**Figure 15.7:** Illustrating the difference between pressure and the force down on a surface. In both A and B the force down is 12 gram force, which is the weight of the three cubes. However, in A the pressure is 4 gram force per square centimetre and in B it is 12 gram force per square centimetre.

## Pressure in liquids

Most of us know that the deeper you go down in water the greater the pressure becomes. For example, there is a limit to the depth to which a submarine may safely dive. Beyond this limit the hull would be crushed.

The apparatus shown in figure 15.8 can be used to demonstrate that pressure increases with depth. The deeper the rubber diaphragm is pushed, the higher the water is forced in the right-hand arm of the manometer.

Ten metres down in water the pressure is double the atmospheric pressure. This pressure is made up of water pressure and atmospheric pressure acting on the surface of the water. Therefore, 20 metres down the pressure would be 3 times the atmospheric pressure, or, simply, 3 atmospheres. Sixty metres down the pressure is 7 atmospheres. This is about the limiting pressure for skin-diving. Very few skin-divers have been able to go deeper.

The apparatus shown in figure 15.8 may be used to demonstrate other facts about pressure in liquids. By bending the copper wire as shown in the right-hand illustration, the rubber diaphragm may be positioned so that it faces sideways or upwards. The pressure recorded is the same each time, provided the depth is constant. This demonstrates that, at a given depth, the pressure exerted by the water is the same in all directions.

Liquids other than water may be tested. With methylated spirits, which is

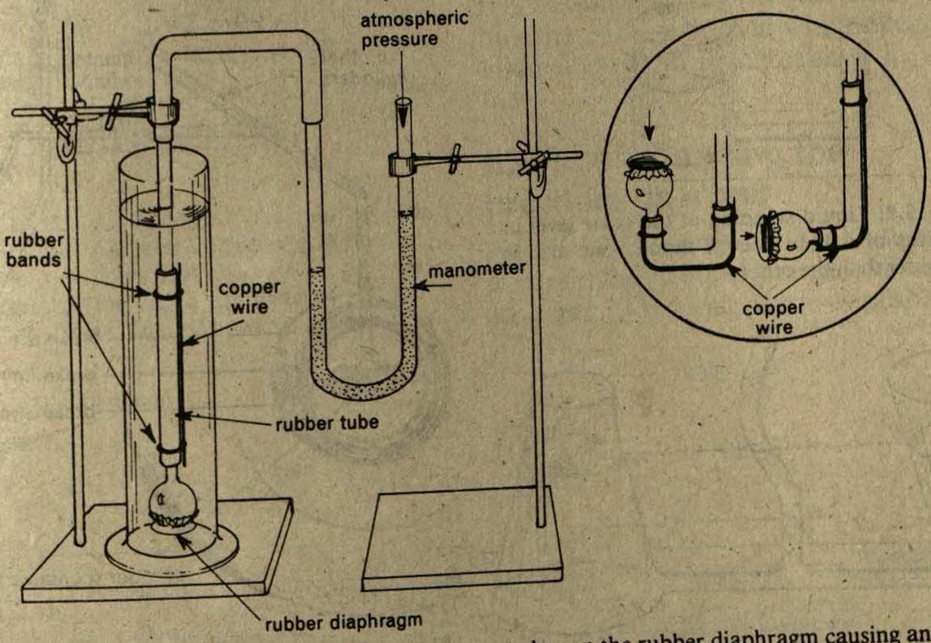


**Figure 15.8:** Pressure increases with depth. The water pushes on the rubber diaphragm causing an increase in pressure in the air in the tube. This pushes up the water level on the right-hand side of the manometer. If you took a reading at twice the depth, you would find you had twice the water pressure. By bending the copper wire, the apparatus may be used to test the pressure downwards and sideways as well as upwards. It will be found that, at any given depth, the pressure is the same in all directions.

less dense than water, smaller pressures are recorded. With carbon tetrachloride, which is denser than water, greater pressures are recorded. From this we conclude that, the greater the density of the liquid, the greater the pressure it exerts.

The apparatus shown in figures 15.9 and 15.10 shows that neither size nor shape of vessels affects the pressure of a liquid. The pressure 5 metres down in a small salt-water pool would be the same as the pressure 5 metres down in the middle of the Pacific Ocean, provided the water densities were the same.

Figure 15.11 explains the working of the hydraulic brake system of a motor car. Pushing on the brake pedal causes an increase in pressure in the oil in the master cylinder. This increase in pressure spreads through all the oil in the system. As a result, the pistons at the wheels move out and push the brake bands against the brake drums.

This example illustrates an important fact about liquids. An increase in pressure is transmitted in all directions throughout a liquid without loss. This is Pascal's Principle and it is true of gases as well as liquids.

Figure 15.12 is a diagram of a car hoist in common use in garages. It, too, depends for its working on the fact that liquids and gases transmit pressure in all directions.

The following is a summary of facts about pressure in liquids.

- Pressure increases with depth.
- Pressure is proportional to the density of the liquid.

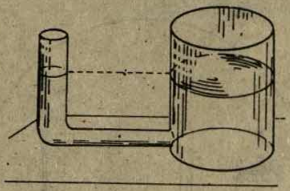


**Figure 15.9:** Liquid standing at the same level in both arms of a U-tube even though one arm is much wider than the other.

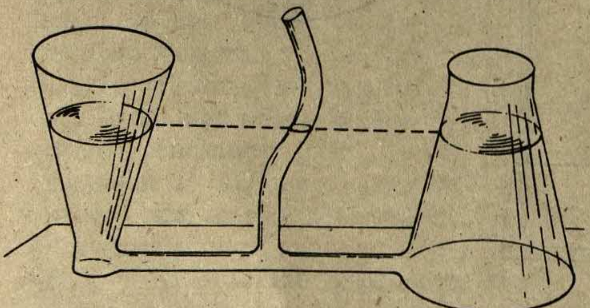


**Figure 15.10:** Pascal's vessels, which show that the pressure in a liquid is the same at the same vertical depth no matter what the shape of the vessels.

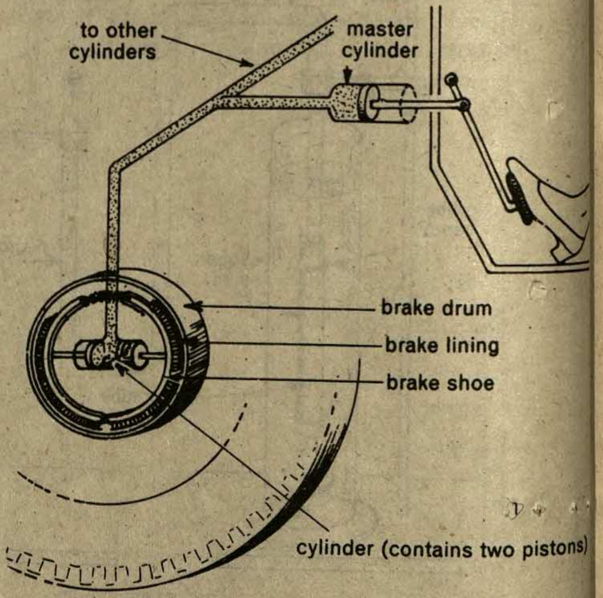


**Figure 15.11:** The hydraulic brake. When the brake pedal is pushed down, the pressure on the oil is increased. This increase in pressure is transmitted through all pipes to each of the pistons in the wheels.

- At a given depth in a liquid the pressure is the same in all directions.
- Pressure is not affected by the shape of the container.
- Applied pressure is transmitted throughout an enclosed liquid without loss.

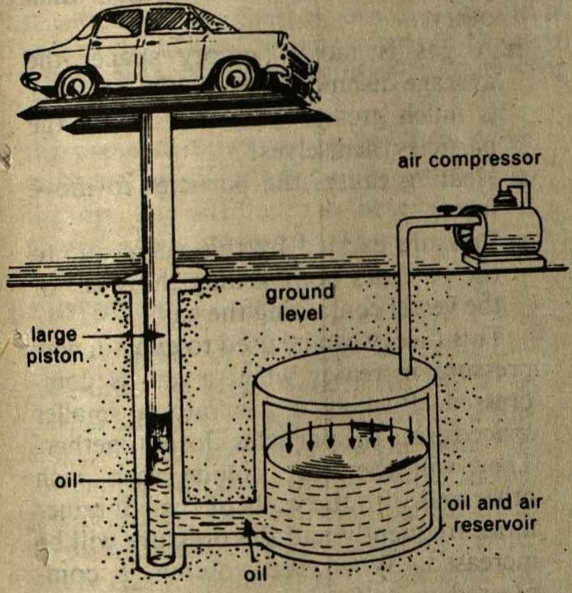


**Figure 15.12:** A simplified diagram of an hydraulic hoist. Air pressure pushes down on the oil in the reservoir. This increase in pressure travels through the oil to the underside of the large piston, which is forced upwards.

## Pressure in the atmosphere

Pressure in liquids is proportional to depth: twice the depth gives twice the pressure. This statement is true even of the great ocean depths of the world. This is so because water is incompressible.

In the earth's atmosphere, however, pressure is not proportional to depth. From the top layers of the atmosphere down to within thirty kilometres of the earth the pressure increases from zero to 0.01 kgf/cm². This is a distance of more than 700 kilometres. In the final thirty kilometres the pressure increases from 0.01 kgf/cm² to 1 kgf/cm². This happens because air is compressible. Each layer of air is compressed by the weight of the layers above it. At sea level the weight of the air above is one kilogram on each square centimetre or approximately 10 tonnes on each square metre. It is for this reason that most of the earth's atmosphere is compressed within the eight kilometres immediately above its surface.

## Effect of changing the pressure on a gas

Figure 15.13 shows an apparatus that measures the effect of change of pressure on a gas. When the piston is pushed in

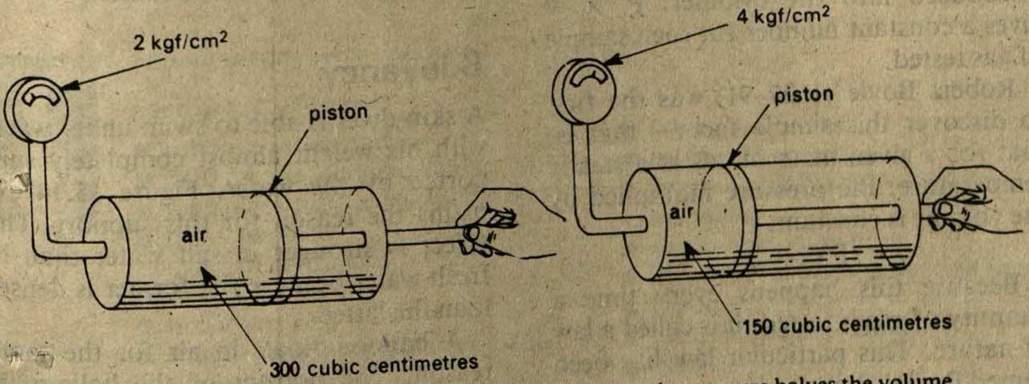


**Figure 15.13:** Increasing the pressure on a sample of gas. Doubling the pressure halves the volume.

the reading on the pressure gauge rises, and when the piston is pulled out the reading drops. Table 15.2 contains some results obtained from such an apparatus.

**Table 15.2:** Increasing the pressure on a sample of gas

| Pressure (P) in kgf/cm$^2$ | Volume (V) in cm$^3$ | P × V |
|---|---|---|
| 1 | 600 | 600 |
| 2 | 300 | 600 |
| 3 | 200 | 600 |
| 4 | 150 | 600 |
| 6 | 100 | 600 |

These results show that, as the pressure is increased, the volume becomes smaller. Doubling the pressure halves the volume and trebling the pressure reduces the volume to one-third. This means that the pressure and the volume will always give the same number when multiplied together. Provided gas is neither added to nor extracted from the cylinder and provided the temperature does not change, we can predict that P × V will always give the same number.

Results similar to those shown in table 15.2 are obtained no matter what gas is introduced into the cylinder. P × V gives a constant number for each sample of gas tested.

Robert Boyle (1627–91) was the first to discover this simple fact — that is, that for a given mass of gas at a steady temperature, the pressure multiplied by the volume is constant.

$$PV = k$$

Because this happens every time a quantity of gas is tested, it is called a law of nature. This particular law has been named Boyle's Law.

## Boyle's Law explained by the kinetic theory of gases

The kinetic theory of gases states the following:

- A gas consists of very small particles in rapid motion in all directions.
- The particles do not all move at the same speed; some move faster than others.
- A gas is mostly empty space; the average distance between the particles is much greater than the size of the particles themselves.
- Heating causes the particles to move faster.
- Pressure exerted by the gas is due to the particles bombarding the walls of the vessel containing the gas.

This theory can be used to explain why pressure increases when a gas is compressed. Pushing a gas into a smaller space forces the particles closer together. They will therefore collide with each other and with the walls of the container more frequently and the pressure will be increased. When the volume is compressed to half, twice as many particles will be in a given space as there were before compression. Collisions with the walls of the container and between particles will therefore be twice as frequent and the pressure will be doubled.

## Buoyancy

A skin-diver is able to swim under water with his weight almost completely supported by the water. Figure 15.14 explains the reason for this support. The effect is stronger in salt water than in fresh water because the former is denser than the latter.

A balloon floats in air for the same reason. The bottom of the balloon is deeper in the air than the top. Therefore

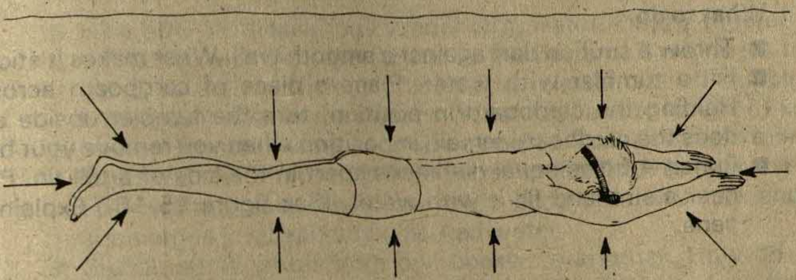


**Figure 15.14:** The buoyant effect of water on a diver. Water pressure acts on all parts of the body. The underneath surface of the body is deeper in the water than the upper surface. Therefore the pressure acting upwards on the body is greater than the pressure acting downwards and the body is buoyed up.

the pressure upwards on the bottom is greater than the pressure downwards on the top. The difference in these pressures gives the balloon its buoyancy.

## Flotation

The weight of a ship is generally measured by the weight of water it pushes aside as it floats. The heavier the ship, the greater this weight and the lower the ship rides in the water. In the past, greedy ship-owners loaded their ships with more cargo than they could safely carry. Some ships were lost at sea because of this overloading. Samuel Plimsoll in 1876 was responsible for the act of parliament that compelled all British ships to display a mark on the vessel's side. This mark shows the depth to which the ship can be loaded safely. (See figure 15.15.)

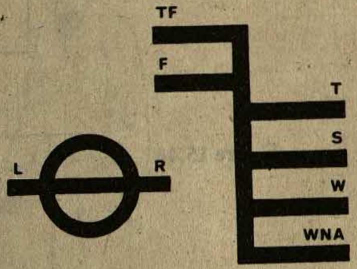


**Figure 15.15:** The Plimsoll line. These are marks on the starboard side of a ship indicating depths to which the ship may be safely loaded. What do the letters mean?

**EXPERIMENT 15.1** *Experimenting with pressure*

**Each group will need:**

- rubber suction dart
- 500 mL measuring cylinder
- long glass tube with tapered end
- glass tumbler
- piece of cardboard
- tall tin
- hot-water bag
- rubber stopper and glass tube to fit hot-water bag
- a strong board
- five house bricks
- two beakers
- length of rubber tubing for siphoning
- round-bottomed flask
- stopper and glass tube to fit flask
- tripod
- retort stand and clamp
- gauze
- Bunsen burner

### What to do

- Throw a suction dart against a smooth wall. What makes it stick?
- Fill a tumbler with water. Place a piece of cardboard across the top. Holding the cardboard in position, turn the tumbler upside down. Why does the cardboard remain in position when you remove your hand?
- Punch 4 holes equal distances apart in the side of a tall tin. Place the tin near a sink and fill it with water. (See figure 15.16.) Explain what happens.

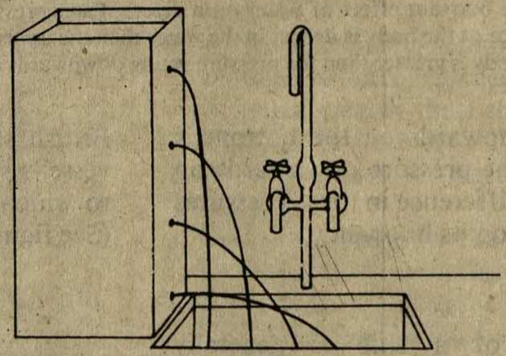


**Figure 15.16**

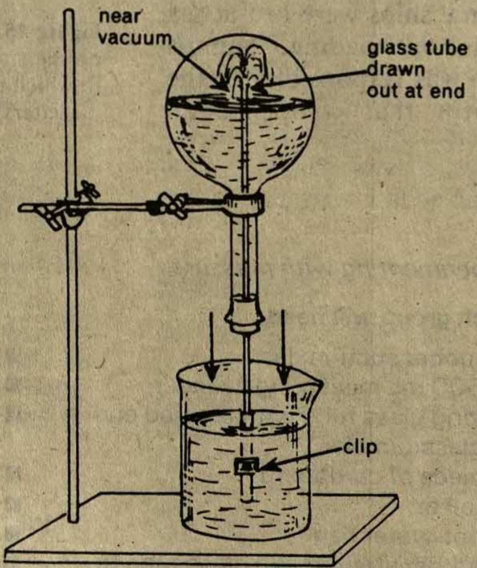


**Figure 15.17:** The fountain experiment. When the clip is loosened, air pressing on the water pushes a stream of water through the glass tube.

- Fill a 500 mL measuring cylinder with water. Place a tapered glass tube in the water with the tapered end at the bottom. Blow down the top end of the tube with sufficient pressure to release one air bubble. Watch the bubble as it rises to the surface. What happens to its size? Explain.
- Make a fountain using a round-bottomed flask and glass tube as shown in figure 15.17. First boil a little water in the flask so that the air is pushed out by the steam. Then invert the apparatus with the end of the tube submerged in a beaker of coloured water.
- Siphon some water from one beaker to another. How do you start the siphon? When do you get the fastest flow? When does the siphon stop working?
- Lift a board with a person on it by blowing into a hot-water bag. (See figure 15.18.) First fit the hot-water bag with a stopper and a glass tube. Place the board on supports on either side of the bag so that you commence lifting with some air already in the bag under the board.

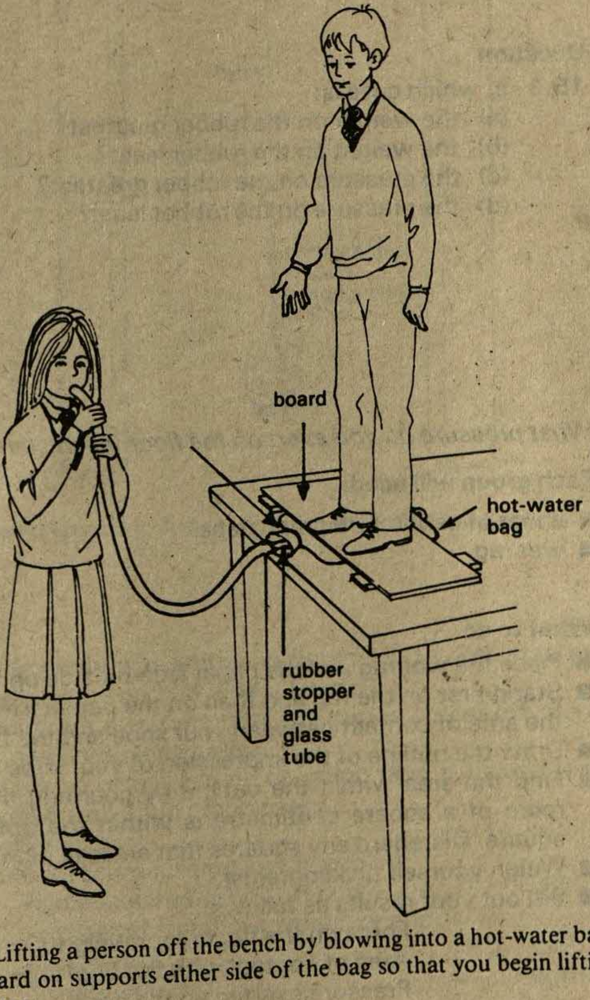

board
hot-water bag
rubber stopper and glass tube

**Figure 15.18:** Lifting a person off the bench by blowing into a hot-water bag. You will need to have the board on supports either side of the bag so that you begin lifting with some air already in the bag.

**EXPERIMENT 15.2**

### *Which face of a house brick exerts the greatest pressure when resting on the bench?*

**Each group will need:**

- house brick
- sheet of foam rubber
- ruler

**What to do**

- Stand the house brick on the sheet of foam rubber.
- Place the ruler flat on the surface of the foam and touching the side of the brick.
- Mark the level on the house brick. This should indicate how far the brick sinks into the foam rubber.
- Repeat by standing the brick on its other faces.

**Question**

**15.1** In which case is:
 (a) the weight on the rubber greatest?
 (b) the weight on the rubber least?
 (c) the pressure on the rubber greatest?
 (d) the pressure on the rubber least?

**EXPERIMENT 15.3**

### *What pressure do you exert on the floor when standing on one foot?*

**Each group will need:**

- sheet of centimetre graph paper
- wet rag

**What to do**

- Place the wet rag and the paper side-by-side on the floor.
- Stand first on the rag and then on the paper. This should give an outline of the area of contact between your shoe and the floor.
- Draw the outline of the impression of your shoe on the paper.
- Find the area within the outline by counting the squares. Where half or more of a square centimetre is within the outline, count it as a whole square. Disregard any squares that are less than half within the outline.
- Weigh yourself (in kilograms).
- Set out your results as follows:

Force on the floor (your weight) = kgf
Area of contact with the floor = $cm^2$
Pressure exerted on the floor = $kgf/cm^2$

EXPERIMENT 15.4

## *What is the pressure on a suction cup when it is loaded to its maximum?*

**Each group will need:**

- rubber suction cup of the type used on the end of toy arrows
- length of stout cord
- sheet of centimetre graph paper
- mass carrier
- kilogram masses

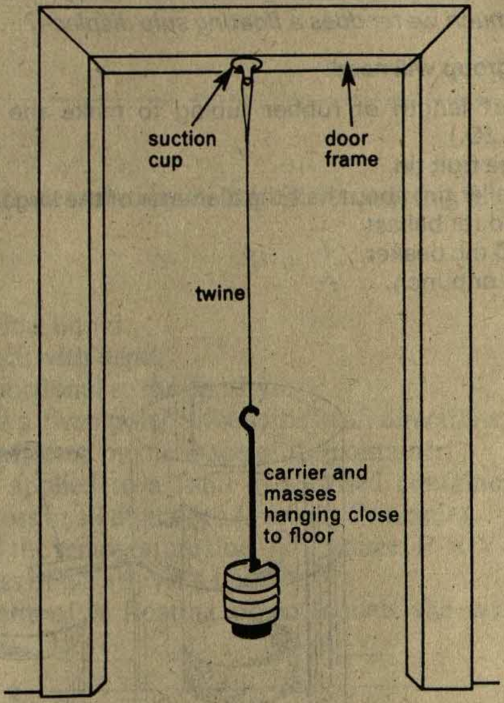


**Figure 15.19:** An experiment to find the pressure holding up a suction cup.

**What to do**

- Set up the apparatus as shown in figure 15.19. Moisten the cup slightly before pushing it up on to the door frame.
- Add one kilogram at a time until the cup is pulled off. Be careful not to have your toes under the carrier.
- Measure the area of the cup by counting (and estimating) the number of squares it covers on 1 cm graph paper.
- Record your results.
- Calculate the pressure holding up the cup.

Force required to pull off cup = kgf
Number of squares covered by cup =
Area of cup = cm²
Pressure on cup = kgf/cm²

**Questions**

**15.2** How does the pressure holding up the suction cup compare with the air pressure at sea level, which is 1 kgf/cm$^2$?

**15.3** Suggest a reason for the difference in pressures.

**15.4** You are given a smaller suction cup of design similar to that of the cup used in this experiment. If its area is 2 cm$^2$, what weight would be needed to pull it off?

**EXPERIMENT 15.5**

### *How much water does a floating ship displace?*

**Each group will need:**

- short length of rubber tubing to make the overflow pipe (See figure 15.20.)
- large fruit tin
- smaller tin, about half the diameter of the larger one
- sand for ballast
- 250 mL beaker
- drill or punch

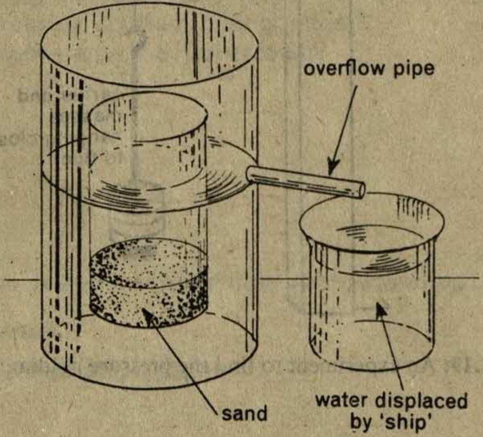


**Figure 15.20:** Measuring the water displaced by a "ship" as it floats.

**What to do**

- Drill or punch a small hole in the side of the large tin, near the top.
- Force a small length of rubber tubing into the hole.
- Add sand as ballast to the small tin so that it floats upright in water.
- Weigh the "ship" on a lever balance.
- Fill the larger tin with water until a little overflows through the tube.
- Weigh an empty 250 mL beaker.
- Lower the "ship" into the larger tin, collecting the displaced water in the beaker.
- Weigh the beaker to find out the weight of water displaced.

- Repeat the experiment a number of times, changing the weight of the "ship" each time.
- Record your results, comparing the weight of the "ship" with the weight of water displaced.

**Question**

**15.5** How did the weight of the ship compare with the weight of water displaced?

## Pressure

- Pressure is measured by stating the force acting on a unit of area.

$$P = \frac{F}{A}$$

- Pressure in a liquid
  - increases with depth
  - is proportional to the density
  - around a given point is the same in all directions
  - is not affected by the shape of the container.
- Pressure applied to a fluid in a closed container is transmitted without loss in all directions (Pascal's Principle).
- Provided the temperature does not change, P × V is constant for a given mass of gas (Boyle's Law).
- The weight of a floating object equals the weight of fluid it displaces.

## Spelling list

atmosphere
ballast
balloon
buoyancy
diaphragm
gauge
hydraulic
kilopascal
manometer
Plimsoll
siphon

## Things to do

**15.6** Demonstrate Pascal's Principle using a tennis ball. Punch holes in the ball with a red-hot metal knitting needle. Fill it with water by squeezing it flat and allowing it to recover its shape while submerged. Take the ball out of the water and squeeze it hard. What happens at the various holes? Does the water come out with equal pressure no matter what the direction of flow?

15.7 Refer to your library to find out about:
 (a) bathyspheres
 (b) diver's bends
 (c) snow cats.

## More questions

**15.8** State three units used for measuring force.

**15.9** State three units used for measuring pressure.

**15.10** State five facts about pressure in liquids.

**15.11** An elephant walking on a lawn at the zoo does not make as deep an impression in the lawn as the high heel of a woman's shoe. Explain.

**15.12** Tyres with a wide track require less pressure than narrow tyres when fitted to the same car. Explain.

**15.13** Draw a diagram of a lift pump showing the positions of the valves during the upstroke. What is the maximum distance the pump can "suck" up water? (R)

**15.14** A mercury barometer has an uneven bore. What effect does this have on the height of mercury supported by the atmosphere?

**15.15** The rear wheels of a car are further from the brake pedal than the front wheels. Does this mean that the pressure exerted at the rear brakes is less than the pressure exerted at the front brakes? Explain.

**15.16** Gases are much less dense than liquids. In what other ways do they differ?

**15.17** Why are dams constructed so that they are thicker at the base than at the top?

**15.18** Some water skiers are able to ski barefooted. Compare the pressures barefooted and when on a ski.

**15.19** What is the fact about gases that is known as Boyle's Law?

**15.20** What happens to the size of the bubbles exhaled by a diver working under water as they rise to the surface?

**15.21** Why is it easier to swim in salt water than in fresh water?

**15.22** What is the effect on the density when the pressure is changed on (a) a gas, (b) a liquid, (c) a solid?

**15.23** What difference would there be between the way a ship floated in the Red Sea and the way it floated in the Great Lakes of Canada?

**15.24** Which would have the greater tendency to sink in air — a balloon inflated with a bicycle pump or one inflated by a person's breath?

**15.25** Hydraulic brakes are ineffective if air is trapped in the pipes leading to the brake cylinders. Why?

**15.26** What is the method used to make a submarine submerge? How is it made to surface?

**15.27** Which exerts the greater pressure on a concrete road — a bulldozer or a semitrailer carrying a bulldozer? Explain.

**15.28** Why are oil and air used in a car hoist instead of air alone?

**15.29** To what depth must a diver descend in fresh water so that the pressure is three times that at the surface?

**15.30** A piece of lead foil, shaped like a boat, floats on water. When rolled into a ball the same piece of lead will sink. Why?

**15.31** Why are balloons that are designed to rise to great altitudes only partly inflated when they leave the ground?

**15.32** Comment on this statement. "A balloon is filled with hydrogen to make it lighter." Compare your answer with that given for question 15.30.

**15.33** Each tyre of a car covers an area of the road 15 × 10 $\text{cm}^2$. If the car weighs 1.2 tonnes (t), what pressure does it exert on the road? (See appendix 1.)

## Test yourself (chapter 15)

In the following questions, choose the best answer and write its letter in your workbook.

1. A large, irregularly shaped rock is placed on a lawn. The rock is turned over so that the area in contact with the lawn is doubled. The pressure the rock now exerts on the lawn
   (a) has been doubled
   (b) has been halved
   (c) is still the same.

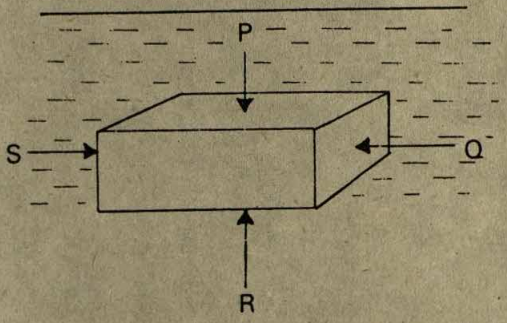


**Figure 15.21**

2. Figure 15.21 shows a block of wood submerged in water. The pressure of water acting on the block would be greatest at
   (a) P
   (b) Q
   (c) R
   (d) S and Q.
3. The pressure would be least at
   (a) P
   (b) Q
   (c) R
   (d) S.

4. The pressure of water acting on the block would be equal at
   (a) P and Q
   (b) P and R
   (c) Q and S
   (d) P, Q, R and S.
5. A ship displaces 22 000 tonnes of water in the Red Sea. In a freshwater lake, where the water is less dense, the ship would
   (a) sink lower in the water but still displace 22 000 tonnes
   (b) sink lower and displace more than 22 000 tonnes
   (c) would not sink as far but still displace 22 000 tonnes
   (d) would sink to the same level as in the Red Sea and displace the same weight of water.
6. The average pressure of the atmosphere at sea level is approximately
   (a) 1 gf/cm$^2$
   (b) 1 gf/m$^2$
   (c) 1 kgf/cm$^2$
   (d) 1 kgf/m$^2$
7. Which of the above pressures is smallest — (a), (b), (c) or (d)?

# 16

# Elasticity

We use elastic materials every day. Many garments contain elastic to keep them in place on our bodies. Women's stockings are elastic; they would be unsatisfactory if they became permanently stretched. Tennis balls contain compressed air. This gives them the elasticity that makes them bounce. Car manufacturers, when designing a new model, subject the springs in the seats to severe tests. This is done to make sure that the seats retain their springiness even after long use.

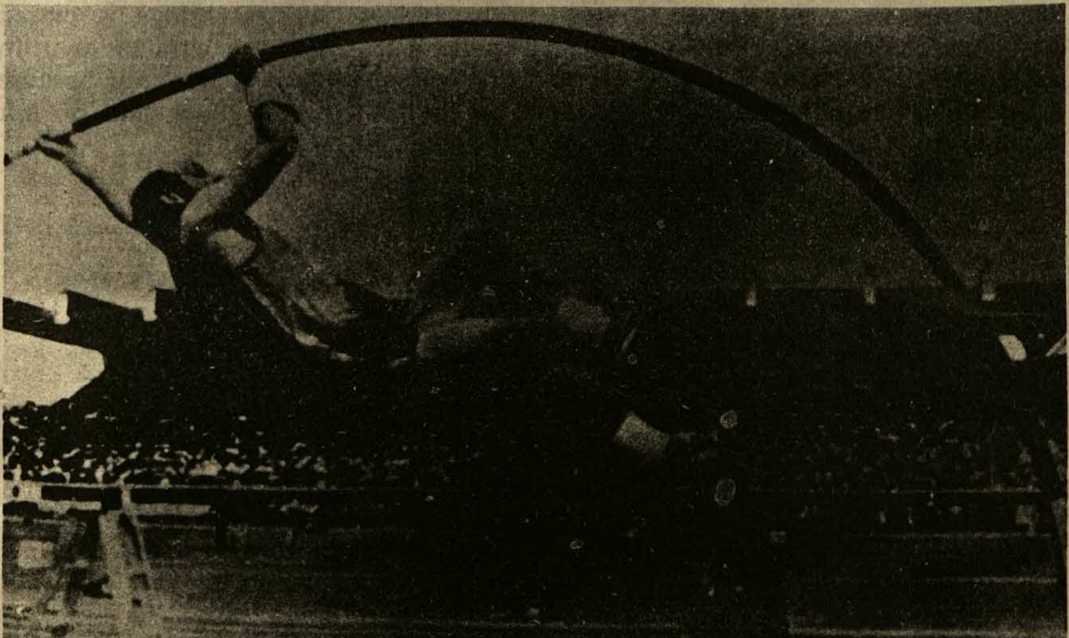


**Figure 16.1:** A pole-vaulter about to make his leap across the bar. On the run-up he digs the bottom of the vaulting pole into the ground. His forward movement then causes the pole to bend. As he rises towards the cross-bar he uses the straightening force of the pole to give him that final flip that carries him over the bar. (Photo courtesy News Ltd)

## Testing for elasticity

Springs are elastic — a good spring will hold its shape even though it is pushed and pulled many times. If an elastic object is forced out of shape, it resumes its original shape when the force acting on it is removed. For example, you can push in a rubber ball by pressing on it with your fingers, but when you release the ball it resumes its original size and shape. On the other hand, if you press on a piece of putty with your finger you make a hole in it and this hole remains when the finger is removed. Putty is therefore not elastic; it is said to be plastic.

## Stress

Forces that cause an object to change its shape or size are called stresses. Stresses may cause one or more of the following changes:

- stretching
- bending
- twisting
- shearing
- compression.

Twisting stress, for example, occurs in the axle of a motor vehicle when the engine transmits its power to the driving wheels. Figure 16.2 shows an experiment set up to test the elasticity of a steel wire when it is twisted in the same way.

Shearing stress occurs in the pin of the drawbar of a tractor (see figure 16.3).

## Strain

Strain is the effect produced by a stress. If a car is overloaded, the springs are flattened and the body is closer to the road. We can see the strain by looking at the springs. A steel bridge is placed under extra stress when a train is on it. In this case we cannot see the strain because the girders are very thick and do not bend much.

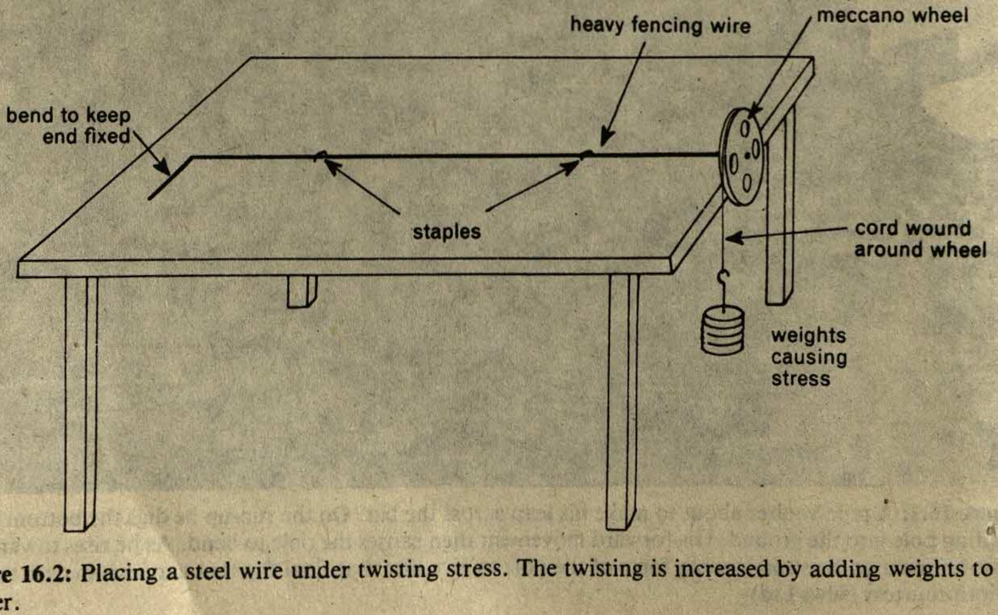


**Figure 16.2:** Placing a steel wire under twisting stress. The twisting is increased by adding weights to the carrier.

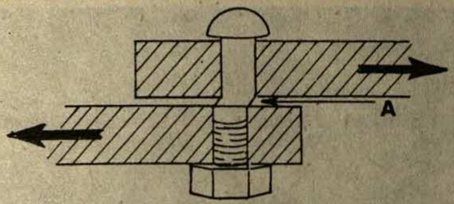


**Figure 16.3:** Showing a bolt under shearing stress. The bolt will eventually be sliced in two at A.

## Measuring the strain caused by a stress

Figure 16.4 shows how the strain may be measured in a coiled spring. When equal weights are placed on the carrier one at a time, it is found that the extra strain is the same each time a weight is added. This is an example of an important fact about elastic springs: twice the load causes twice the stretch. Three times the load causes three times the stretch.

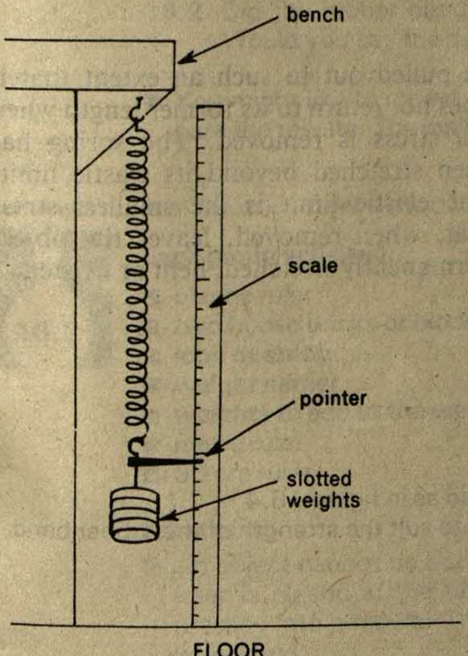


**Figure 16.4:** Measuring the strain when weights are added to a coiled spring.

This fact was first stated by Robert Hooke (1635–1703). When a stress is applied to an elastic object, the strain produced is proportional to the stress that causes it.

Experiment 16.2 is designed to find out whether this fact also applies to the bending of a beam.

## Compression of materials

All gases are elastic. This property is made use of in tyres, air cushions and air beds. Some cars are sprung on air instead of steel springs and are advertised as floating on fluid.

Energy is needed to compress gases. This energy is stored in the compressed gas and is therefore called potential energy. When the gas is allowed to expand this potential energy is released and may be used to do work. An example of this is the work done by expanding steam in the steam turbine. (See figure 16.5.)

Liquids and solids also are elastic when compressed. However, the compression produced is so small that, compared with gases, liquids and solids are generally regarded as being incompressible.

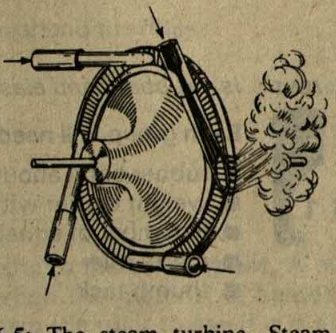


**Figure 16.5:** The steam turbine. Steam under pressure provides the energy. The flow of expanding steam is directed against the blades of the turbine and sets it spinning.

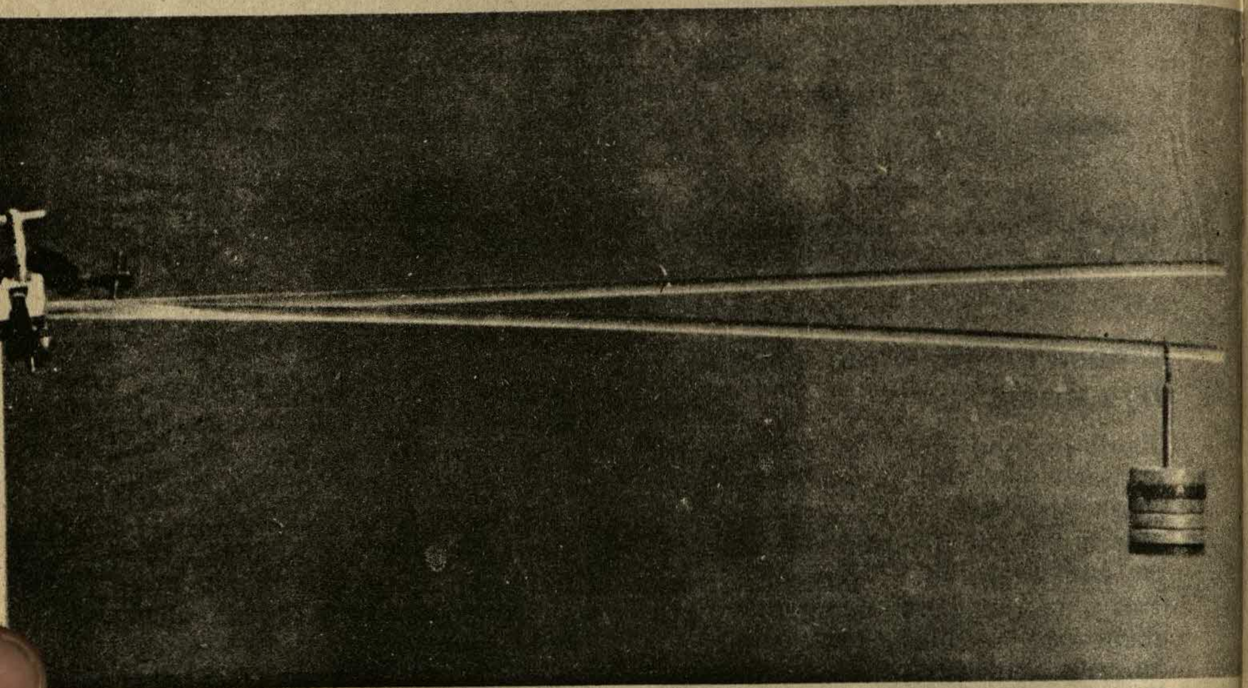


**Figure 16.6:** A glass rod bends very easily. It is perfectly elastic because it straightens again when the weight is removed. In this photo two glass rods are shown clamped together. A weight is placed on only one rod.

## Elastic limit

We have said that elastic materials are those that if stretched, bent, twisted or compressed, recover completely when the stresses are removed. However, there is a limit to the stress that may be applied. A spiral spring, for example, may be pulled out to such an extent that it does not return to its former length when the stress is removed. The spring has been stretched beyond its elastic limit. The elastic limit is the smallest stress that, when removed, leaves the object permanently stretched, bent or twisted.

**EXPERIMENT** *Is a rubber band elastic?*

**16.1**

**Each group will need:**

- rubber band about 10 cm long
- weight carrier with pointer attached as in figure 16.4
- a number of equal slotted weights to suit the strength of the rubber band
- metre ruler
- thumb tack

**What to do**

- Suspend the rubber band from the end of a bench with a thumb tack. If preferred, the rubber band could be looped on to a clamp on a retort stand.

- Attach the weight carrier to the other end of the rubber band. This should take any kinks out of the band. Record the level of the pointer on the metre ruler, held as in figure 16.4.
- Add equal weights one at a time and record the stretch for each weight added. Do not strain the rubber too much or it may be taken beyond its elastic limit.
- Remove the weights one at a time and record the shrinkage for each weight taken off.
- Record your results as follows:

| Total no. of weights on carrier | Reading on metre scale during loading | Stretch for each weight added | Reading on metre scale during unloading | Shrinkage for each weight removed |
|---|---|---|---|---|
| | | | | |

**Questions**

**16.1** Was the rubber band stretched by approximately equal amounts for each weight added? What was the average stretch for each weight added?

**16.2** Did the rubber band fully recover once the weights were removed? Would you say the rubber band was perfectly elastic?

- You might like to repeat the experiment using a steel coiled spring and compare the results. The inside of an old roller blind yields a suitable spring.

**EXPERIMENT 16.2**

*Is a "plastic" ruler elastic?*

**Each group will need:**

- plastic ruler
- two house bricks or blocks, on which to suspend the ruler
- loop of string
- weight carrier
- weights to add to the weight carrier
- metre ruler
- 30 cm ruler

**What to do**

- An object cannot be both plastic and elastic to the same stress. A plastic ruler is plastic at the time it is made, when the material is heated and pressed into a mould. This experiment tests the ruler to see if it is elastic when cold.
- Place the ruler in a horizontal position, resting on and suspended between two blocks.

- Tie a loop around the middle of the ruler.
- Add equal weights one at a time and measure the sag for each weight added.
- Remove the weights one at a time and measure the rise for each weight removed.
- Tabulate your results in the same way as for experiment 16.1.

**Question**

**16.3** Did the ruler sag by equal amounts for each weight added? If it did not, calculate the average sag. Was there any great difference between a particular sag and the average? Did you find that the ruler was elastic?

## Elasticity

- Stress when applied to an object may cause stretching, bending, twisting, shearing or compression.
- Strain is the deformation produced by the stress.
- An elastic object is one that recovers its original shape and size when the stress is removed.
- A plastic material is one that can be permanently deformed and moulded by forces.
- The elastic limit is the smallest stress that will permanently deform an object.
- Stress is proportional to strain as long as the elastic limit is not reached.

## Spelling list

compression
deformation
elastic
incompressible
shearing
springiness
stress
stretch
twisting

## Things to do

**16.4** Test an old hacksaw blade for elasticity. Bend it slightly and see if it becomes perfectly straight again when released. How far can you bend it before a permanent change occurs? What is the change: does the blade become permanently bent or does it snap?

**16.5** Load a piece of nylon fishing line or a nylon stocking to see whether the stretch follows Hooke's Law. Does it recover fully when the load is removed?

**16.6** Test some steel ball bearings for elasticity. Allow one to drop on to a thick glass or steel plate. Notice how far it rebounds upwards. Compare this rebound with that of a tennis ball dropped from the same height.

## More questions

**16.7** Explain the meanings of the words "stress" and "strain".

**16.8** What is meant by the elastic limit of a spring?

**16.9** A long rubber eraser is bent nearly double. What kinds of stresses are caused in the different parts of the rubber?

**16.10** A spiral spring stretches 3 cm when loaded with a 1 kg weight. (a) How much would ½ kg stretch it? (b) What weight would stretch it 2 cm? (See appendix 1.)

**16.11** Are trees elastic? Explain.

**16.12** What is plasticine? Why is it so named?

**16.13** Most "plastic" articles are elastic. Explain this contradiction.

**16.14** Scales used for weighing can be designed to work with levers or with springs. Which type would be preferable in a shop? Why?

**16.15** An experiment to find the relation between the bending of a beam and its load gave the following results.

| Load (kg) | 10 | 20 | 30 | 40 | 50 | 60 | 70 |
|---|---|---|---|---|---|---|---|
| Bending (cm) | 0.20 | 0.40 | 0.60 | 0.84 | 1.00 | 1.16 | 1.40 |

Plot these values, making the loads vertical and the bendings horizontal. Is any law illustrated here?

**16.16** Sometimes an aircraft crash is due to the body breaking because of metal fatigue. What is meant by the term "metal fatigue"? (R)

## Test yourself (chapter 16)

Write the answers in your workbook.

1. A perfectly elastic spring is compressed 3 cm by a load of 5 kg. What load would be needed to compress the spring 12 cm?
2. A spring is suspended and loaded with weights in the way shown in figure 16.4. The following table gives the extensions for the various weights added.

| Load (kg) | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Total length (cm) | 52 | 54 | 56 | 58 | 60 |

Provided the spring is perfectly elastic, what would be its length if another 3 kg were added?

3. Which of the following statements best explains the meaning of elasticity?
   (a) An elastic substance bends easily and then recovers completely when the force causing the bending is removed.
   (b) An elastic substance recovers its original shape and volume when deforming forces are removed.
   (c) An elastic substance can be bent, twisted, compressed or sheared without changing its shape.

# 17

# Waves

We live in a world of energy. Much of this energy is locked up waiting to be released. Examples are the chemical energy in petrol and the potential energy of water held back in a dam.

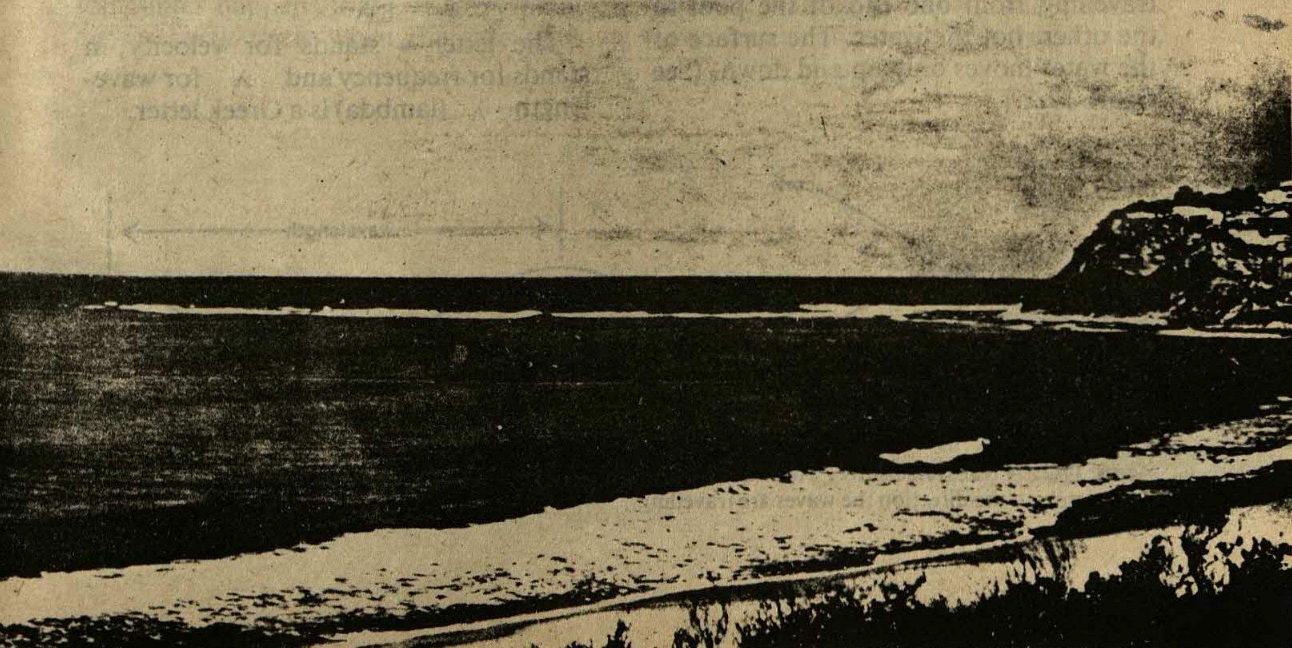
When energy is released it often travels through space. Think of light and heat travelling outwards from the sun, or the radio energy transmitted by our broadcasting stations. And our bodies are constantly bombarded by the energy that produces sound when it strikes our ears.

How does all this energy move? Is it as lumps of matter, that is, particles; or does it travel as waves? Before we can answer this question we need to know something about waves.

## Waves carry energy

Figure 17.1 is a photograph of a cliff facing the ocean. Many many years ago the face of this cliff was much further out to sea. The waves have worn it away to its present position, where pieces of the cliff lie broken at its base. Looking at this picture we realize how enormous is the work done by waves. Waves are carriers of energy.

**Figure 17.1:** The work of the waves. Many years ago the headland extended much further out to sea, as the length of the reef indicates. This is the southern headland of Newport Beach, New South Wales.



## Energy to make waves

The waves of the ocean are made by the wind. The stronger the wind, the bigger the waves. The wind contains kinetic energy and some of this energy has been used to build the waves.

Many homes have their own swimming pools. These pools can be used to study waves, particularly when the sun is shining. Waves may be generated by moving a long piece of wood up and down horizontally on the surface of the water. The sunlight forms a wave pattern on the floor of the pool. It will be noticed that these wave patterns all appear to travel at the same speed across the floor of the pool. This is so whether the waves are a long or a short distance apart, and whether they are big or small. At the same time, remember that you are using energy to make the waves.

## Transverse waves

If we throw a cork into the middle of a swimming pool we notice that it bobs up and down as the waves travel along the surface of the water. From this we can conclude that it is the waves that are travelling from one end of the pool to the other, not the water. The surface of the water moves only up and down. (See figure 17.2.)

## Wavelength and frequency

A ripple tank may be used to study transverse waves more accurately. A piece of wood vibrates or oscillates at one end of the tank to generate waves that travel along the tank. Figure 17.3a shows a wave pattern formed when the vibrator is oscillating slowly. Figure 17.3b shows the pattern when the vibrator is moving more rapidly. By comparing these two photographs we can see that the more rapid the oscillations, the shorter is the *wavelength*. The rate at which the waves are formed is called the *frequency*: the greater the frequency, the shorter the wavelength.

It can be shown that when the frequency of the waves is doubled, the wavelength is halved. In other words, the product of the frequency and the wavelength of the waves remains the same. This product is the speed of the wave. If, for example, we know the wavelength is six centimetres and the frequency is two waves per second, then we can conclude that the waves are travelling at twelve centimetres per second.

$$\text{speed (or velocity)} = \text{frequency} \times \text{wavelength}$$

$$v = n\lambda$$

The letter v stands for velocity, n stands for frequency and $\lambda$ for wavelength. $\lambda$ (lambda) is a Greek letter.

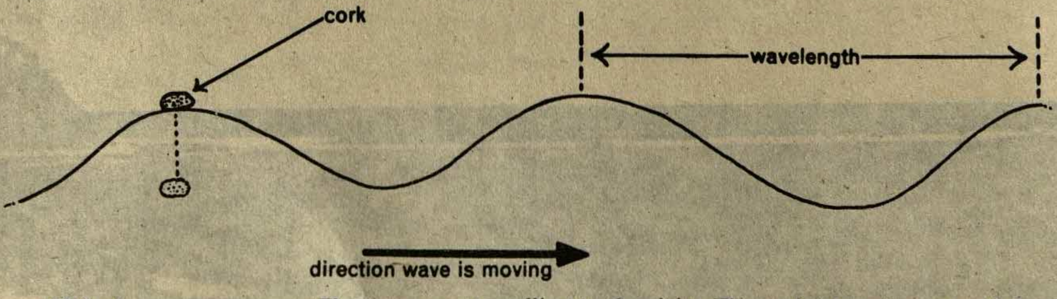


**Figure 17.2:** A transverse wave. The waves are travelling to the right. The cork is moving up and down transversely to the direction the waves are travelling.

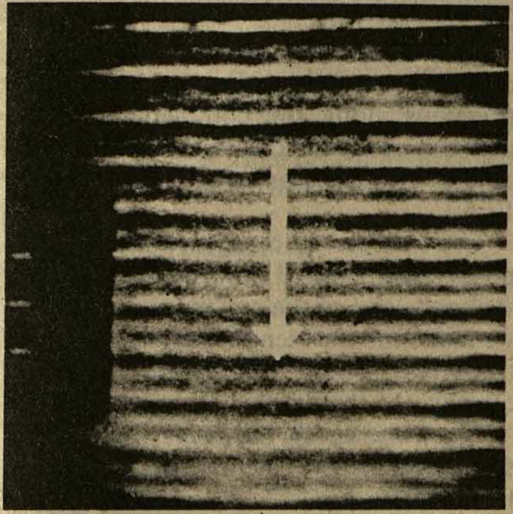


**Figure 17.3a:** Waves in a ripple tank generated by slow vibrations.

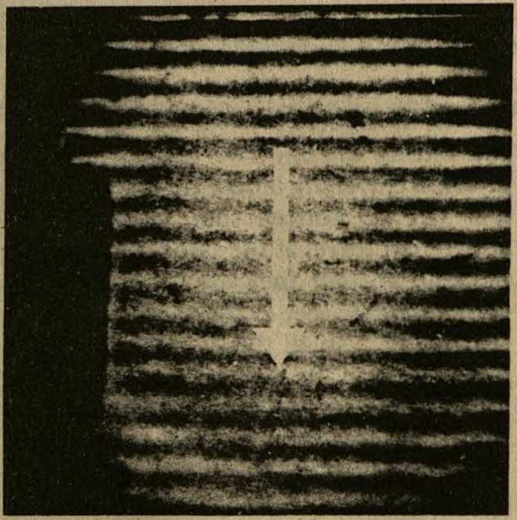


**Figure 17.3b:** Waves in a ripple tank generated by rapid vibrations.

The wavelength in the left-hand photo is longer than the wavelength in the right-hand photo.

## Compression waves

So far we have been studying transverse waves. But these are not the only kind of waves. Another kind is the compression wave.

A compression wave occurs during blasting operations, for example. It sometimes happens that windows many metres away rattle when the face of a quarry is dynamited to dislodge rock. The explosion pushes the air so that it is compressed, and this compression travels outwards as a wave. This sudden increase in pressure rattles the glass when it strikes the window. From this we can see that compression waves, like transverse waves, are carriers of energy. Also like transverse waves, compression waves require energy to form them.

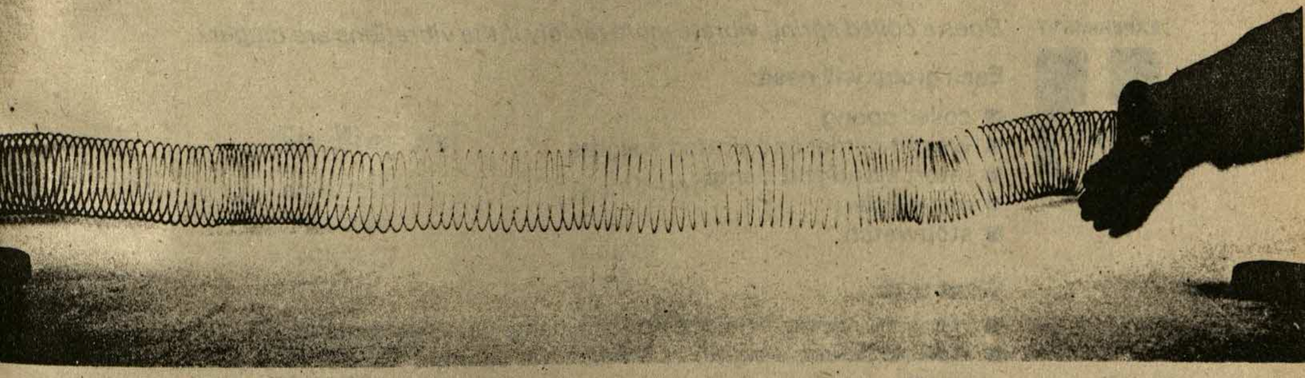


**Figure 17.4:** Compressions travelling along a coiled spring.

Compression waves may be studied by using a long coiled spring called a slinky. By suspending the slinky on threads, as shown in figure 17.4 (previous page), and hitting the end, we can see a compression travelling along the spring.

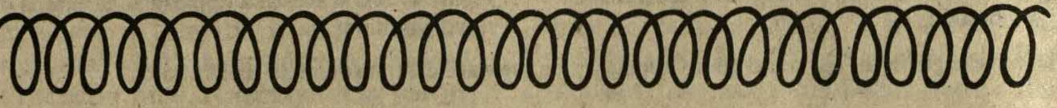
It will be noticed that compressions apparently travel at the same speed along the coil whether they are large or small compressions. (See experiment 17.2.)

If we tie a small piece of white thread to one loop of the coil, we notice that the loop moves forwards and backwards as the compression passes. As with transverse waves, it is the wave that travels forward, not the material that is carrying the wave.

By hitting the end of the spring regularly we can send a series of compressions along the coil. The distance between compressions is the wavelength of the compression wave. (See figure 17.5.)

The number of compressions passing per second is called the frequency. If we strike the end of the coil more frequently we make the wavelength shorter. As with transverse waves, the greater the frequency, the shorter the wavelength.

The velocity of the waves along the spring can also be calculated by using the formula $v = n\lambda$.



undisturbed spring

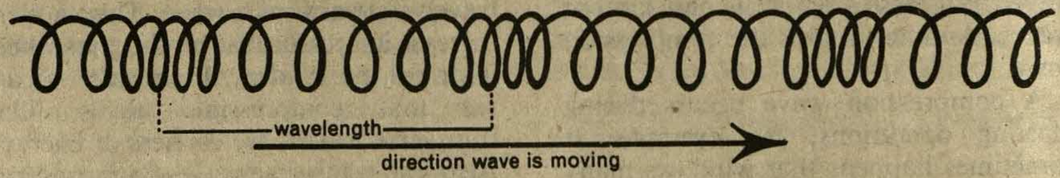


**Figure 17.5:** A compression wave. The compressions are travelling to the right. Each loop of the coil moves forwards and backwards as the waves pass.

### EXPERIMENT 17.1

*Does a coiled spring vibrate more rapidly if the vibrations are bigger?*

**Each group will need:**

- coiled spring
- weight carrier and slotted weights
- retort stand and clamp
- metre ruler
- stopwatch

**What to do**

- Hang the spring from the end of a clamp on a retort stand.
- Add sufficient weights to stretch the spring by about one quarter of its length.

- Pull the carrier down 2 or 3 cm and release it.
- Using a stopwatch, time 50 vibrations. One vibration is a complete up-and-down movement.
- Stop the spring moving and set it vibrating again, this time with twice the displacement (also known as amplitude).
- Time 50 vibrations as before.
- Do this a number of times or pool the class results.

**Question**

**17.1** Did the spring vibrate more rapidly or more slowly when the displacement was larger?

**EXPERIMENT 17.2** *Do big waves travel faster than small waves in a horizontal coiled spring?*

**Each group will need:**

- long coiled spring (called a slinky) suspended on threads, as in figure 17.4
- stopwatch

**What to do**

- Hang a coiled spring as in figure 17.4.
- Strike one end gently and, using a stopwatch, measure the time for the compression to travel the length of the spring.
- Wait until the reflected waves have subsided.
- Now strike the spring with more energy. Time this compression also.
- Repeat this a number of times or pool the results of the class.

**Questions**

**17.2** What was the average time for:
  (a) small compressions
  (b) large compressions?

**17.3** What was the measurement that differed most from the average of the times for (a) the small compressions, (b) the large compressions?

**17.4** Would it be reasonable to conclude that all compressions travel at the same rate along the spring?

## Spelling list

compression
dynamite
frequency
generate
kinetic
longitudinal
oscillate
plumb-bob
quarry
radiate
ripple
transverse
vibrate

## Waves

- Waves carry energy.
- Energy is required to produce waves.
- The wave travels, not the material carrying it.
- There are two kinds of waves, transverse waves and compression waves.
- Small waves travel at the same rate as big waves in the same medium.
- The greater the frequency the shorter the wavelength.

## Things to do

**17.5** Make a pendulum using a plumb-bob and a length of cord. Suspend the pendulum by clamping the end of the cord between two halves of a cork held in a clamp on a retort stand. Time 50 vibrations of the pendulum. How is this time affected if (a) the weight of the bob is changed, (b) the displacement of the swing is changed, (c) the length of the cord is changed?

**17.6** Experiment with a child's swing. Count the number of complete to-and-fro swings in a minute. How is this number affected if (a) a heavier child is on the swing, (b) the swing is made to move with a bigger displacement?

**17.7** Watch and count waves in a swimming pool, or sea waves from a headland. Count the number of waves passing a given point per minute (the frequency). Estimate the speed of the waves by watching one particular wave for a minute. Hence calculate the wavelength.

**17.8** Make a Crova's disc to demonstrate compression waves. From a sheet of thick white cardboard, cut out a circular disc 30 cm in diameter. Draw a small circle of 0.5 cm radius in the centre. (See figure 17.6.) Divide this small circle into 8 equal parts as shown. Using the points A, B, C . . . in turn as centres, draw circles with radii 1.5 cm, 2 cm, 2.5 cm, etc. Continue drawing circles until the disc is filled. Accentuate each circle with centre A by drawing it in red. Punch a hole in the centre of the disc so that it may be placed on the turntable of a record player. Cut out a second piece of cardboard, 30 cm square. Cut a slot 26 cm by 1 cm across the middle. Support this square centrally over the disc on the turntable. Turn on the turntable and view the rotating disc through the slot. This will give you a very good impression of moving compression waves.

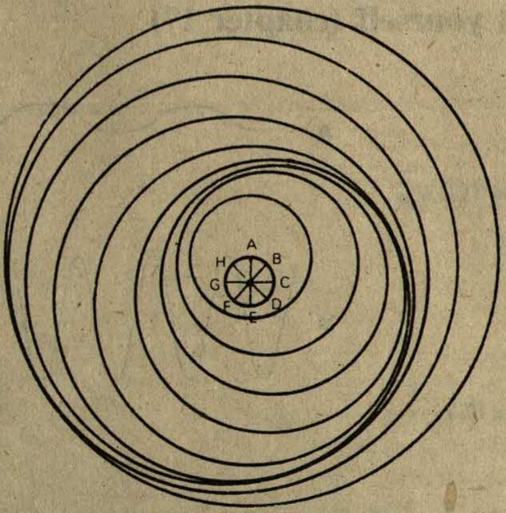


**Figure 17.6:** A Crova's disc, used to demonstrate compression waves.

## More questions

**17.9** Draw a diagram to show the shape of a wave formed on the surface of water. Show several crests and troughs. Indicate the wavelength.

**17.10** Draw another diagram of a water wave, with the same wavelength as the previous one, but carrying more energy.

**17.11** During rescue operations in a stormy sea, the size of the waves may be reduced by pouring oil on the water. Explain this.

**17.12** Draw a compression wave in a coiled spring. Mark in the wavelength.

**17.13** Draw a second compression wave, with the same wavelength as in question 17.12 but carrying more energy.

**17.14** Waves are generated and are travelling across the surface of a pool with a wavelength of three centimetres. How may the wavelength be lengthened to six centimetres?

**17.15** Waves are passing at the rate of two every second. If the wavelength is thirty centimetres, how fast are the waves travelling?

## Test yourself (chapter 17)

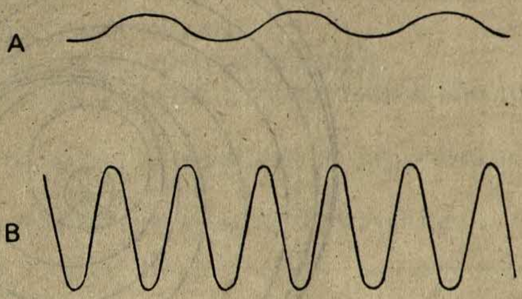


**Figure 17.7**

1. The waves in figure 17.7 were generated at different times. Which wave has the greater
   (a) wavelength
   (b) frequency
   (c) energy
   (d) amplitude (displacement)?
2. A series of waves are travelling at 30 cm/s. Three crests pass a given point every second. What is
   (a) the frequency
   (b) the wavelength?

# 18

# Sound and hearing

Of all our senses, hearing is perhaps the most important. Some people might disagree with this statement and say that sight is the most important. However, language is an extremely important human ability and it is far more difficult to teach a totally deaf baby to speak than a blind baby. Babies learn to speak by listening to the language of those around them. How do you teach a deaf child to speak words that it cannot hear? Unless a deaf child goes to a special school, staffed by highly trained teachers, he or she will go through life both deaf and dumb. He or she will be unable to communicate except by body movements.

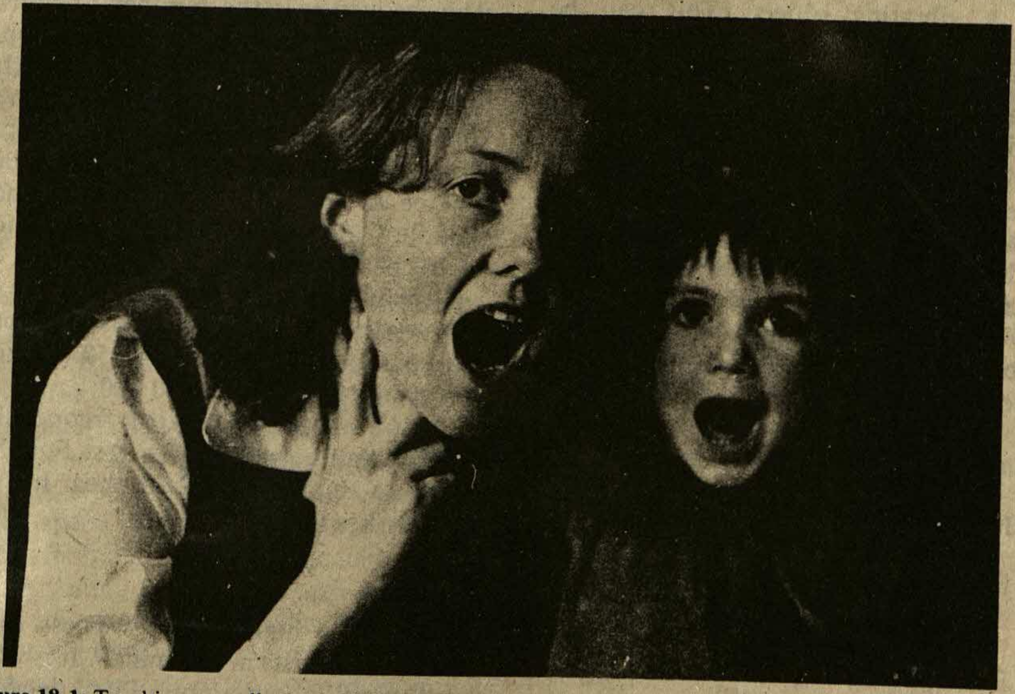


**Figure 18.1:** Teaching a totally deaf child to speak. Here the child is looking into a mirror to watch her own and her teacher's lips. At the same time she has her hand on the teacher's throat so that she can feel the vibrations that are producing the sound.

## What is sound?

Suppose we pluck a guitar string. Four things are happening as we hear the sound.

- The guitar string vibrates.
- The air carries these vibrations to the ear.
- The ear picks up the vibrations and changes them into pulses of electricity.
- The brain tells us that these pulses are a note from a guitar.

In this chapter we shall discuss these four things that are all involved when we hear a sound.

## Vibrating objects

For a sound to be produced there must be a vibrating object. This can be demonstrated with many examples. During the playing of the guitar we can actually see and feel the vibrations of the strings. However, it is not only the strings that vibrate, but also the body of the instrument. This can be proved by placing sawdust on the guitar body. When a string is plucked the sawdust dances on the wood.

Table 18.1 is a list showing what vibrates in some musical instruments to produce the sound.

**Table 18.1:** How various sounds are made

| Instrument | What vibrates |
|---|---|
| harp | strings |
| xylophone | wooden strips |
| trumpet | lips |
| pipe organ | air |
| saxophone | reed |
| flute | air |
| drum | parchment |

The list in table 18.1 shows what starts the sounds. In each case, however, these vibrations set a whole object or instrument vibrating. Even the harp is built on a box of air. This vibrates, increasing the volume and improving the quality of the notes.

When we speak or sing, strips of membrane called vocal cords vibrate. These set the air in the throat and mouth vibrating. Because no two people have exactly the same shaped throat and mouth, everybody's voice sounds different. The removal of tonsils and adenoids could be a serious operation for a professional singer. It would change the shape of the throat and might upset the quality of the notes produced when singing.

## Frequency of vibration

The frequency is the number of vibrations per second. One vibration is a complete to-and-fro movement of the vibrating object. The lowest note on a pipe organ has a frequency of 10 vibrations per second. The squeak of a bat can be as high as 120 000 per second. Middle C on the piano has a frequency of 262 per second.

Humans can hear sounds ranging in frequency from 20 to 20 000 vibrations per second, a dog from 15 to 50 000 and a porpoise from 150 to 150 000.

As we age, the range of frequencies that we can hear becomes less. For this reason a child can generally hear higher frequencies than its parents.

## Pitch

Pitch is the highness or lowness of a note. Pitch exists in our minds. It is what we "think" about a note. Pitch depends on the frequency. The greater the frequency, the higher is the pitch.

## Difference between a note and a noise

A musical note is formed by a series of regular vibrations. Middle C is formed by vibrations with a frequency of 262 per second. There are, however, traces of other frequencies in the disturbance. These traces of other frequencies are different if middle C is played on different instruments. These extra frequencies are called overtones; they give character to a musical note. They help us to distinguish, for example, between the same note played on a harp or a banjo.

A noise is caused by a lot of irregular vibrations. Unlike a musical note, there is no regular pattern in the vibrations producing a noise. Figure 18.2 shows the vibrations of a note without overtones, a musical note of the same pitch with overtones, and a noise.

Some musical instruments produce noise rather than notes. Drums are an example. Bass drums produce noise of low pitch, whereas kettle drums produce noise of a higher pitch.

## Transmission of sound

Sound will not travel through a vacuum. This can be demonstrated by suspending a bell in a large glass jar and pumping out the air. When the apparatus is shaken the bell is inaudible.

Sound will travel through air, water, wood, steel or any other elastic material. The speed of sound differs according to the material carrying it. (See table 18.2.)

A tuning fork forms sounds because of the to-and-fro movement of the prongs. Each time a prong moves outwards, the layer of air in contact with it is compressed. This compression is pushed away from the prong. When the

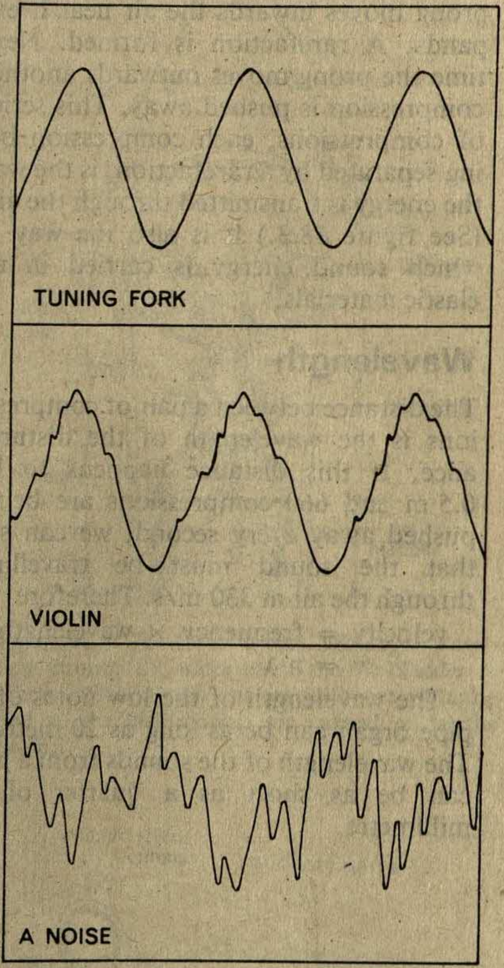


**Figure 18.2:** Wave patterns of the vibrations from a tuning fork, a violin and a noise. The compressions were picked up on a microphone and changed to these patterns by an oscilloscope.

**Table 18.2:** Speeds of sound in different materials

| Material | Approximate speed |
|---|---|
| air | 330 m/s |
| water | 1500 m/s |
| wood | 4500 m/s |
| steel | 6000 m/s |

prong moves inwards the air near it expands. A rarefaction is formed. Next time the prong moves outwards another compression is pushed away. This series of compressions, each compression being separated by a rarefaction, is the way the energy is transmitted through the air. (See figure 18.3.) It is also the way in which sound energy is carried in all elastic materials.

## Wavelength

The distance between a pair of compressions is the wavelength of the disturbance. If this distance happens to be 0.5 m and 660 compressions are being pushed away every second, we can see that the sound must be travelling through the air at 330 m/s. Therefore

velocity = frequency × wavelength

$$v = n \lambda$$

The wavelength of the low notes of a pipe organ can be as long as 20 metres. The wavelength of the sounds from a bat can be as short as a quarter of a millimetre.

## The ear

Hearing is one of our five senses (the other four are sight, touch, smell and taste). The sense of hearing is more highly developed in humans than in any other animal. This is so not only because of the ear but also because of the large brain. The brain gives meaning to the vibrations.

To some extent hearing is like the sense of touch. The nerve endings in our skin can tell us from which direction a breeze is coming, but our skin is incapable of detecting the very rapid changes of pressure that occur in a sound wave.

Fish have a line of very sensitive patches along their bodies. These patches can detect quite small disturbances in the water and allow the fish to "hear" what is happening near it. This is almost a sixth sense and fish use it, for example, to keep close together when swimming in a shoal.

Some fish, however, do have true ears. The air bladder inside the body picks up

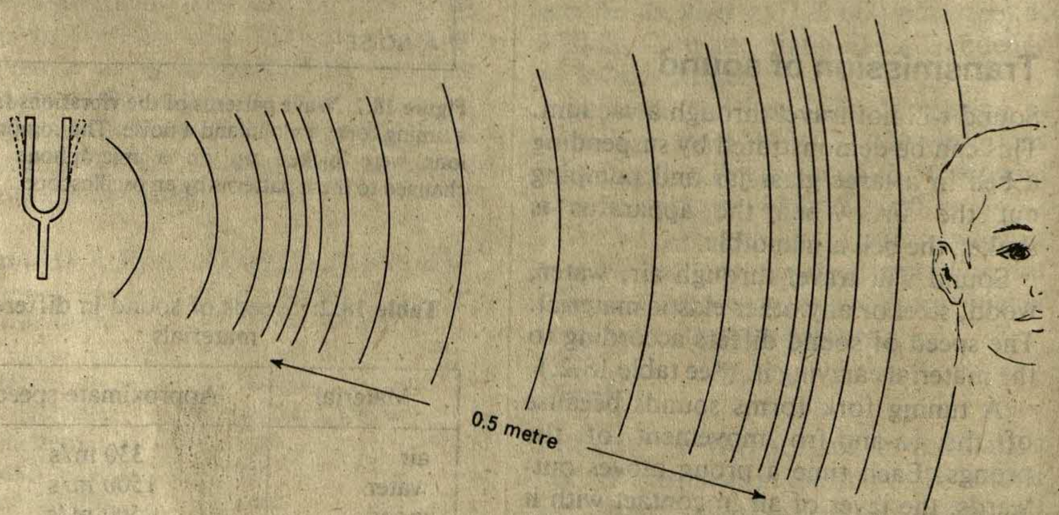


**Figure 18.3:** The formation of a compression wave by a tuning fork. The prongs of the fork are moving to and fro with a frequency of 660 cycles per second. The wavelength is about 0.5 metre.

the vibrations. These are passed on to the brain through a series of bones similar to the bones in the middle ears of mammals. (See figure 18.4.)

We shall now examine the human ear in detail to see how vibrations in the air are changed to messages in the brain. Such a study of the ear leaves us with a deep feeling of wonder. The minute and complex detail of its construction is amazing. No human has ever made anything to approach it.

Looking at figure 18.5 we see that the ear has three sections:

- the outer ear
- the middle ear
- the inner ear.

***The outer ear***. This includes the visible part of the ear and the canal leading to the eardrum. The outer ear collects and channels the vibrations of the air. But it does more than this. It causes the vibrations to resonate and therefore to become stronger. It does this in the same

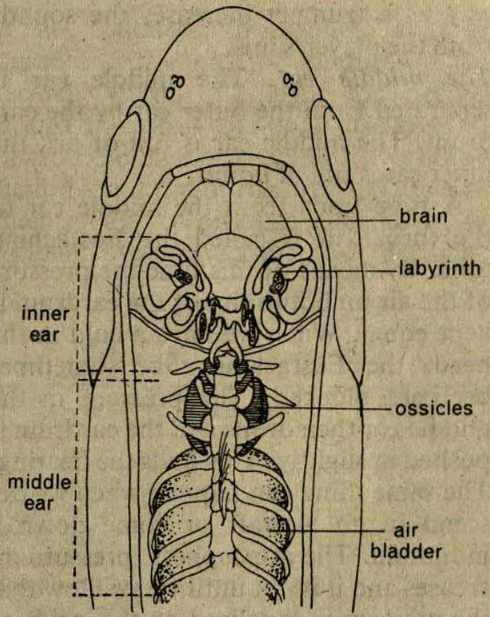


**Figure 18.4:** The ear of a fish. Vibrations travelling through the water cause the air bladder to vibrate. This in turn sets special bones vibrating and so the disturbances are carried on to the brain.

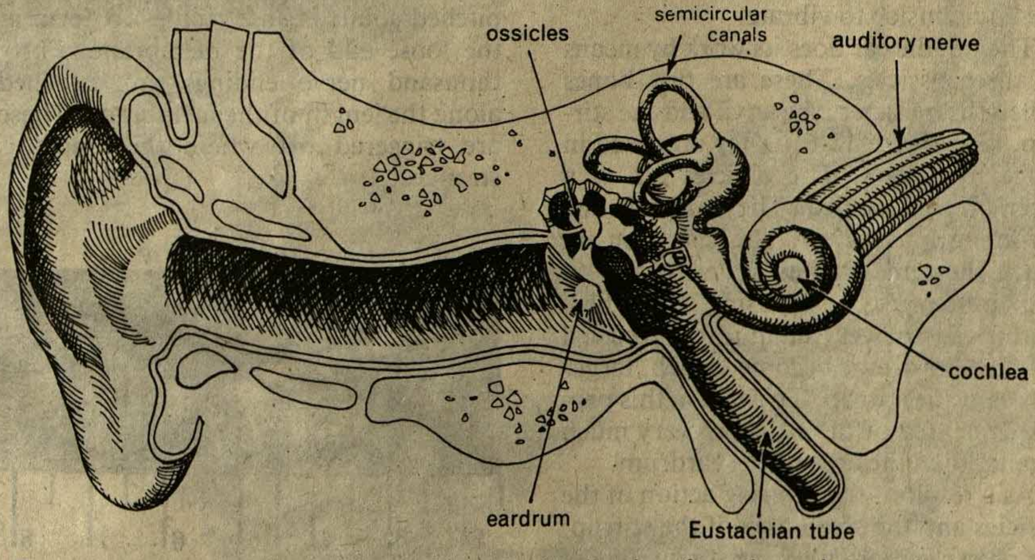


**Figure 18.5:** The human ear. The ossicles transfer the vibrations from the eardrum to the cochlea. The cochlea changes pulses of pressure to pulses of electricity. The auditory nerve carries these pulses to the brain.

way as a trumpet increases the sounds from the player's lips.

***The middle ear***. The middle ear is separated from the outer ear by the eardrum. The middle ear is full of air, the inner ear is full of liquid.

A tube leads from the middle ear to the throat. It is called the Eustachian tube. By means of this tube the pressure of the air on both sides of the eardrum is kept equal. When we have a cold in the head, the Eustachian tube sometimes becomes blocked. The pressure in the middle ear then drops and the eardrum is pushed in slightly. This dulls the hearing. The same thing can happen when we descend in an aircraft or come down a mountain. The atmospheric pressure increases and it is not until we swallow that the pressure is equalized on the inside of the eardrum.

The middle ear is necessary to set the liquid in the inner ear vibrating. Liquid is practically incompressible. If there were no middle ear, sound waves would bounce off the inner ear without causing the liquid inside to vibrate.

The middle ear does its work by means of three ossicles. These are tiny bones called the hammer, the anvil and the stirrup. (See figure 18.6.) They are fixed in place by sinews. The ossicles act as a lever on the cochlea. They magnify the incoming pushes on the eardrum in much the same way as a man is able to shift a heavy stone by using a crowbar. In this way the very small forces received on the eardrum become much larger forces at the stirrup. To assist in this process, the area of the stirrup is very much smaller than the area of the eardrum.

As a result of the levering action of the ossicles and the small area of the stirrup, the pressure exerted by the stirrup on the cochlea is very much greater than the pressure of the sound wave on the eardrum. In this way waves are formed in the liquid inside the inner ear.

The ossicles serve another purpose. They protect the inner ear from damage by very loud noises. Loud noises trigger off two sets of muscles. One of these tightens the eardrum, thus reducing the vibration; the other set of muscles pulls the stirrup away from the inner ear.

***The inner ear***. The inner ear contains the cochlea and the semicircular canals. The canals give us our sense of balance.

The cochlea converts the vibrations of the liquid in the inner ear to electrical pulses. It is a spiral tube that, if rolled out straight, would be about four centimetres long. It is filled with a liquid similar to spinal fluid.

The cochlea contains a membrane running the whole length of the spiral. This membrane is thin and tight near the stirrup and thick and loose at the other end. When the stirrup vibrates against the cochlea it causes ripples to run along this membrane. High-pitched sounds affect the tight end of the membrane; low-pitched sounds cause ripples to form at the loose end of the membrane. Forty thousand nerve endings are attached along the length of the membrane. These are triggered off where the ripple is strongest.

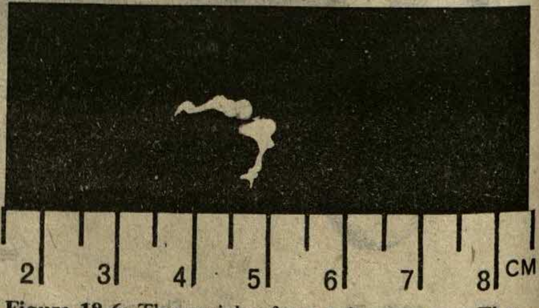


**Figure 18.6:** The ossicles from a human ear. The hammer is shown above the anvil. Part of the stirrup has been cut away.

When a nerve in the cochlea is excited, it sends a pulse of electricity to that part of the brain that deals with hearing. This part of the brain then sends the message to the memory section. Here the message is recognized and the person then understands what he has heard. However, very little is known about the way in which this happens.

## Loudness

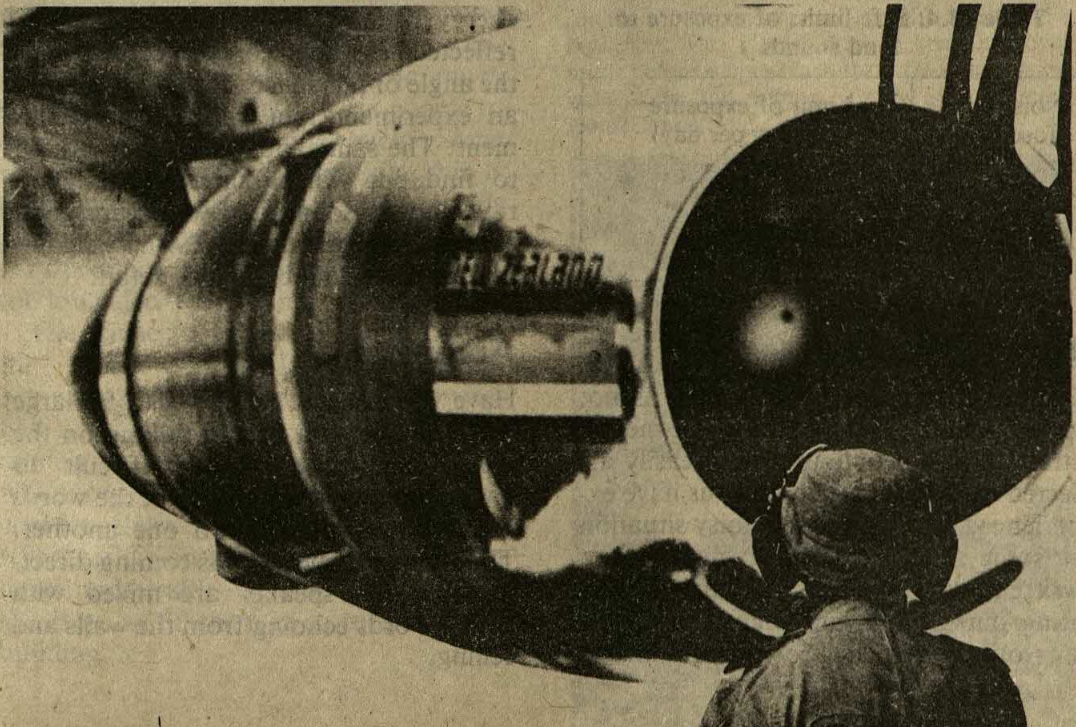
The loudness of sounds depends on the size (amplitude) of the vibrations. Large vibrations produce loud sounds. This may be demonstrated using a drum with sawdust sprinkled over its surface. A gentle tap on the parchment produces a soft noise and little up-and-down movement of the sawdust. If the parchment is struck strongly, a loud noise is produced and the sawdust jumps quite considerably.

The loudness of sounds can be measured. The unit of loudness is the decibel. Table 18.3 gives the decibel ratings of various sounds. It also gives an idea of the energy required to produce them. Notice that it requires 100 times as much energy to produce a sound of 40 decibels as to produce one of 20 decibels.

**Table 18.3:** Loudness scales

| Sound | Energy level | Decibel rating |
|---|---|---|
| Whisper | 1 | 20 |
| Quiet voice | 10 | 30 |
| Quiet radio | 100 | 40 |
| Normal conversation | 1 000 | 50 |
| Average radio | 10 000 | 60 |
| Two-stroke mower | 1 000 000 | 80 |
| Aircraft engine | 10 000 000 000 | 120 |
| Jackhammer | 100 000 000 000 | 130 |

**Figure 18.7:** Wearing ear muffs to protect the inner ears while working in a very noisy environment.



Many people have defective hearing because of over-exposure to loud sounds. A person travelling constantly in heavy traffic or working with noisy industrial machinery is particularly vulnerable. It is generally thought that this kind of deafness is due to damaged eardrums, but this is not so. The real centre of damage due to noise is the cochlea. We mentioned above that the cochlea contains 40 000 hair-like nerve cells, each connected to the brain through the auditory nerve. Prolonged noise can cause these cells to swell and eventually collapse. When this happens the damage is permanent. You can therefore understand why it is important for people using noisy machinery to wear ear muffs and why machines like jackhammers should have silencers.

Table 18.4 gives information about the maximum lengths of time you should allow yourself to be exposed to different loud sounds.

**Table 18.4:** Safe limits of exposure to loud sounds

| Noise level (decibels) | Limit of exposure (minutes per day) |
|---|---|
| 100 | 50 |
| 110 | 25 |
| 120 | 5 |

## Noise pollution

Continual noise, even though it is not harmful to the cochlea, can cause mental stress. Some people are more easily affected than others, but all of us have experienced frustration in a noisy situation at some time. Imagine trying to do a written exam with a jackhammer operating outside the building, or trying to sort out a problem in your relationship with someone dear to you while the traffic roars by outside.

Excessive noise late at night can prevent people from getting adequate sleep. Many countries now have noise pollution laws that make it an offence to operate noisy machinery or to have noisy parties at times when most people sleep.

## Reflection and absorption of sound

Most of us have heard echoes. The best echoes are heard in mountain valleys where there are large flat cliffs. Echo Point, in the Blue Mountains of New South Wales, is a lookout with huge sandstone cliffs on the far side of the gorge. It is famous for the echoes that the valley produces. An empty house with no carpets or curtains produces echoes as we walk on the bare floor. The sound of our footsteps is reflected off the bare walls.

Sound, like all forms of transmitted energy, may be reflected. When reflected, the angle of reflection equals the angle of incidence. Figure 18.8 shows an experiment that verifies this statement. The same apparatus may be used to find out which materials are good reflectors of sound and which are good absorbers. Experiment 18.4 investigates this aspect of sound in more detail.

## Acoustics

Have you ever sat at the back of a large hall listening to a person talking on the stage? Sometimes it is difficult to understand what is being said; the words seem to be running into one another. This happens when words coming directly from the speaker are mixed with earlier words echoing from the walls and ceiling.

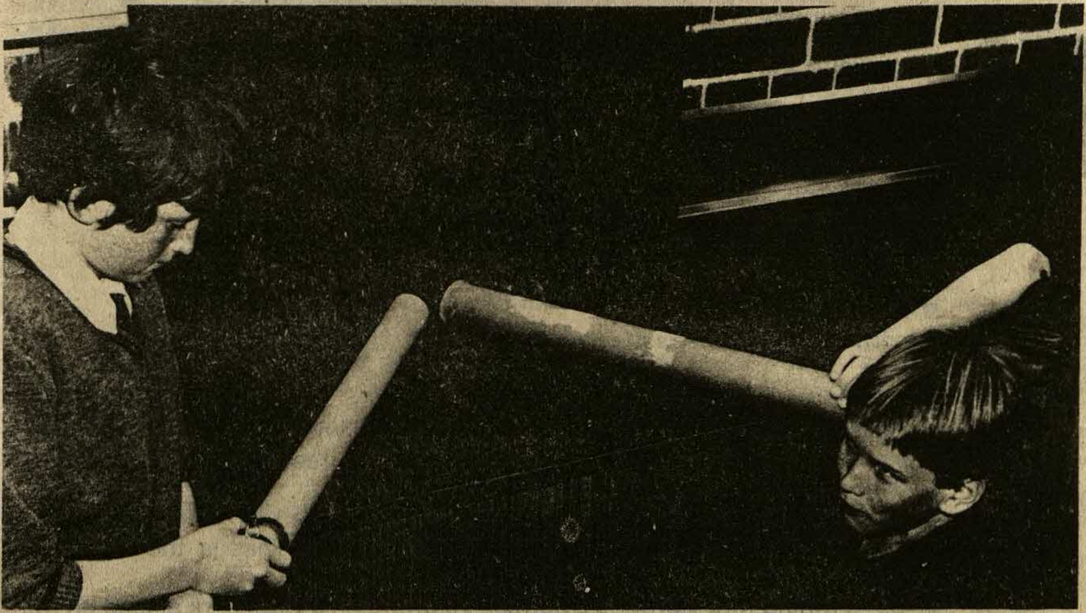
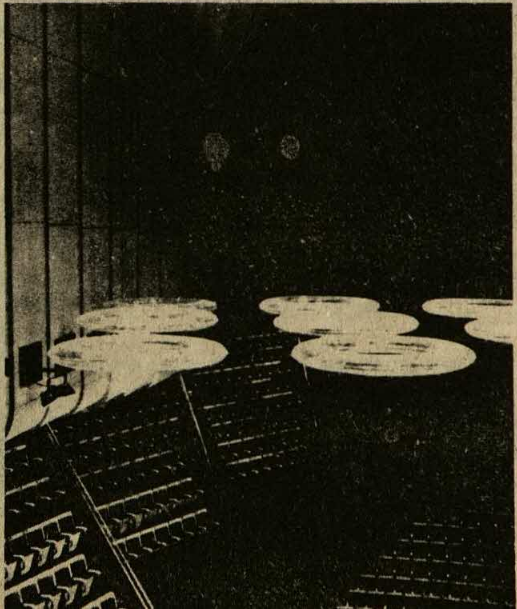


**Figure 18.8:** Apparatus used to investigate the reflection of sound.

Designers of modern theatres and concert halls take steps to reduce this effect. Echoes could be avoided completely by using thick carpet, heavy drapes and special soundproof material for the ceiling. But this would absorb too much sound and make it difficult for people to hear comfortably at the back. Some reflection is therefore essential. This is done by having sections of smooth walls and panels in positions where the echoes they produce will not reach the listeners too long after the original sounds.

The science of sound as it is related to the design of buildings is called acoustics. When designing a new concert hall or theatre, architects generally use models to study the way sound waves will move through the building. This enables them to locate those places where reflection of sound is likely to produce undesirable echoing effects, and therefore avoid them in constructing the building.

**Figure 18.9:** Some of the acrylic rings suspended above the concert platform of the Sydney Opera House. By offering a hard surface immediately above the platform, these rings reflect some of the sounds of the instruments straight back to the musicians. This enables them to hear their own music before echoes reach them from the distant walls of the hall. (Photo courtesy Sydney Opera House Trust)



**EXPERIMENT 18.1**

## *Making sounds*

**Each group will need:**

- narrow-necked bottles of different heights
- ruler
- sonometer with movable bridge
- tuning forks and large cork
- comb and greaseproof paper
- metal tubes of different lengths and thicknesses
- string
- bicycle wheel
- comb and piece of tissue paper

**What to do**

- Hold a ruler firmly on the end of the bench with most of it projecting beyond the edge. Make sounds by flicking the free end. Try the effect of varying the length of the part that is vibrating.
- Rest a bicycle upside down on the floor. Spin the rear wheel and make sounds by holding a ruler against the spokes. What is the effect of speeding up the wheel?
- Set a tuning fork vibrating by striking a prong on a large cork placed on the bench. Hold the vibrating fork against a thin stream of water. Experiment with different forks. What do you notice about the pitch of the note and the length of the vibrating prongs?
- Set the string on a sonometer vibrating. Slide a bridge beneath the wire. How is the length of the wire related to the pitch of the note? What is the effect on the note when the wire is first tightened and then loosened?
- Blow across the neck of an empty bottle. Try different bottles. Try adding some water to a bottle first.
- Tie a length of string tightly around the end of a metal tube. Hold the end of the string and strike the suspended tube with a hard object. How does the pitch of the note produced depend on the length of the tube? Does the weight of the tube have any effect?
- Fold a piece of tissue paper over a comb and play a tune by humming on to the paper.
- Use the following table to tabulate your results.

| What is it that vibrates? | What has to be done to produce a note of higher pitch? |
|---|---|
| | |

**EXPERIMENT 18.2**

## *Does changing the amplitude alter the timing of a pendulum?*

**Each group will need:**

- pendulum bob
- thread
- cork sliced in two lengthways
- retort stand with clamp
- stopwatch

**What to do**

- The amplitude of a vibration is the maximum distance a bob or wire swings from its rest position.
- Cut a cork lengthways. Tie a thread to a pendulum bob. Clamp the free end of the thread between the two halves of the cork. Make the length of the thread about 50 cm.
- Set the pendulum vibrating with an amplitude of about 2 cm.
- Measure the time for 50 vibrations.
- Measure the time for 50 vibrations when the amplitude is 4 cm and when it is 6 cm.

**Questions**

**18.1** What did you find out about the times taken at various amplitudes?

**18.2** A harpist plucks a certain string gently. He then plucks the same string strongly. In comparing the second note with the first, state what happens to

(a) the loudness of the note
(b) the frequency of the vibration
(c) the pitch of the note
(d) the amplitude of the vibration
(e) the energy of the vibration.

**EXPERIMENT 18.3**

## *Making a sonometer vibrate at the same rate as a tuning fork*

**Each group will need:**

- sonometer with movable bridge
- tuning fork giving upper C

**What to do**

- Choose a sonometer fitted with several tight wires and a movable bridge.
- Pluck the wires in turn. Set the tuning fork vibrating on the sonometer. Use the wire that gives a note a little lower than the tuning fork.
- Fit a movable bridge under this wire.
- Pluck the wire and move the bridge along until the wire is giving the same note as the tuning fork.
- When the wire and the fork are almost in tune beats will be heard. These beats make a throbbing sound. The closer the tuning, the slower is the throbbing.

### Questions

**18.3** What would happen to the pitch of the note given off by the wire if it were (a) shortened, (b) tightened, (c) lengthened?

**18.4** You are given two wires — one light, the other heavy. Which one would you use to produce a high note when fitted to a musical instrument?

**18.5** How does a piano-tuner tune a piano? Does he have a tuning fork to match each string on the piano? (R)

**EXPERIMENT 18.4** *Reflection and absorption of sound*

### Each group will need:

- two long cardboard tubes, as shown in figure 18.8
- wristlet watch
- sheet of paper and pencil
- pieces of different materials with which to test the absorption and reflection of sound. Suggested materials: masonite, perforated masonite, flat glass, corrugated cardboard, insulating fibreglass.

### What to do

- Set up the apparatus as shown in figure 18.8 (page 193).
- Place the watch in the end of one of the tubes. Stand or clamp a piece of masonite on the bench to act as a reflecting board.
- Listen for the ticking reflected along the second tube. Adjust the angle between this tube and the board to give the loudest ticking.
- Using a pencil and paper, outline the edge of the reflecting board and the directions of the two tubes. Mark in the normal to the board.
- Measure the angles of incidence and reflection.
- Repeat a number of times and state your conclusion.
- Set the two tubes in the positions where they give the loudest reflected tick.
- Remove the masonite reflecting board and replace it with another piece of material.
- Tabulate your results, placing the best reflector first and the poorest last.

### Question

**18.6** Poor reflection of sound may be due to either absorption of the sound or to scattering. Is there any way of finding out what is happening?

## Spelling list

absorption
amplitude
auditory
bass
cochlea
decibel
frequency
oscillate
ossicle
pitch
rarefaction
resonate
sonometer
stirrup
transmission
vacuum
vocal cord

## Sound and hearing

- Sound waves are compression waves carried by elastic materials.
- The wavelength is the distance between compressions.
- The frequency is the number of compressions passing per second.

$$v = n\,\lambda$$

- The greater the frequency, the higher the pitch of the note.
- The greater the amplitude of the vibration, the louder is the note.
- The ear converts compression waves into pulses of electricity. The brain interprets these pulses as sounds.

## Things to do

**18.7** Use a microphone and a CRO (cathode-ray oscilloscope) to examine the waves produced by a tuning fork. Examine the waves produced when you speak into the microphone. Does whistling produce a pure note? Notice the wave forms for loud and soft notes.

**18.8** In a swimming pool, make sounds under water by knocking two rocks together. Can someone at the other end of the pool hear the sound with the ears (a) above the surface of the water, (b) beneath the surface?

**18.9** Make a string telephone with two jam tins and a piece of string. Punch a hole in the bottom of each tin and thread the string through the holes. Knot each end so that the string is taut when the tins are pulled apart. Use one tin as a microphone and the other as the earpiece.

**18.10** Drill a hole in one end of a ruler. Tie a piece of string to the ruler and whirl it round your head. What causes the sound that is produced?

**18.11** Use a length of garden hose as a speaking tube.

**18.12** Make a stethoscope out of a filter funnel, a T-piece and three pieces of rubber tubing.

**18.13** Examine a gramophone record (preferably a 78) under a hand lens. Try to find out how the vibrations are transferred to the gramophone needle. Are they sideways or up-and-down movements?

**18.14** Measure the speed of sound in air using a starting pistol and a stopwatch. Select two positions at least 1000 metres apart. Fire the pistol at one position and have a stopwatch at the other. Start the watch when you see the smoke and stop it when you hear the report.

## More questions

**18.15** What is the difference between a musical note and a noise?

**18.16** Name musical instruments that use vibrations of (a) strings, (b) lips, (c) reeds, (d) air.

**18.17** Devise another experiment to find the speed of sound in air. What answer would you expect?

**18.18** A man is singing in a hall. He sings a note with 100 vibrations per second. What is the wavelength of the note? Approximately how many compressions would there be between you and the singer if you were 30 metres away? (See appendix 1.)

**18.19** What causes echoes? In what sort of place would they be most likely to occur?

**18.20** A clap of thunder always comes *after* a flash of lightning. Why does this happen?

**18.21** Why do your ears sometimes "pop" when you have a cold and blow your nose strongly?

**18.22** Why does a harp sound different from a banjo?

**18.23** What part does the middle ear play in hearing? What purpose does the Eustachian tube serve?

**18.24** How are the vibrations picked up by the inner ear?

**18.25** Some violins are very expensive. Try to find out why one violin sounds much richer than another. (R)

**18.26** What is sonar? How are shoals of fish detected by using sound waves? How can sound be used to measure the depth of water under a boat? (R)

**18.27** Bats have a remarkable sense of navigation when flying in the dark. They can even avoid a single wire stretched across their flight path. How do they do it? (R)

**18.28** What is the sound barrier? At what speed must an aircraft be travelling to break the sound barrier? (R)

**18.29** How would two spacemen communicate while walking on the surface of the moon? (R)

## Test yourself (chapter 18)

In questions 1 to 8, write the missing words in your workbook.

1. Sound is transmitted by a ______ wave.
2. Echoes are produced by the ______ of sound.
3. The part of the ear most likely to be damaged by prolonged exposure to very loud noise is the ______.
4. The louder the note, the greater the ______ of the vibrations that produce it.
5. The clap of thunder is heard after the lightning flash because sound travels ______ than light.

6. A sound wave with a frequency of 660 vibrations per second is travelling at 330 m/s. Its wavelength is ______.
7. Sound is produced in a trumpet by the vibration of the ______.
8. A note produced by an object vibrating 300 times per second would have a ______ wavelength than one produced by an object vibrating 400 times per second.

In questions 9 to 12, choose the best answer and write its letter in your workbook.

9. A tuning fork vibrating 312 times per second produces a note. A second tuning fork vibrating 256 times per second produces a note that is
   (a) lower in pitch
   (b) higher in pitch
   (c) louder
   (d) softer.
10. You would expect sound to travel fastest in
   (a) a vacuum
   (b) air
   (c) water
   (d) steel.
11. You would expect sound to travel slowest in
   (a) a vacuum
   (b) air
   (c) water
   (d) steel.
12. The reflection of sounds in a room could be best reduced by covering the walls with
   (a) tiles
   (b) wooden panels
   (c) curtains
   (d) very rough cement.

# 19

# Communicating

## Only humans speak

Humans are the most intelligent of all animals. They alone use words and know their meaning. Words can express ideas and feelings. They can describe animals, places and events — real or imaginary, past, present or future. They can also be used just for fun!

The way words are used is called language. The study of the way languages work is called linguistics.

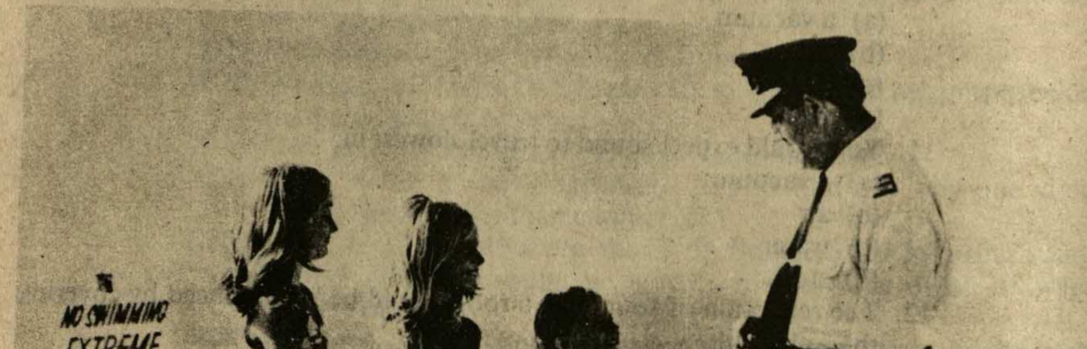


**Figure 19.1:** Look at the expressions on the faces of these people, and the ways they are standing. Notice the positions of their hands. What are the feelings of the policeman? Is he friendly, out of patience or aggressive? Do you think he might be hiding his feelings? What are the feelings of the girls? Does the girl on the left have feelings different from the other two? (Photo courtesy John Fairfax and Sons Ltd)

Words may be written or spoken. We often feel that written language is "more correct" than spoken language (and it may be, because we can go back and correct our mistakes). But modern linguists like to emphasize that the spoken language is the primary one. Every normal human being grows up able to speak the language the people around him use, but people everywhere have to be taught to read and write.

There are many different languages in the world and, of course, if you want to use a particular language, you must know the meaning of each word used. Here is the way "woman" is written and spoken in several different languages.

| Language | Written word | How it sounds when spoken |
|---|---|---|
| English | woman | woman |
| French | femme | fum |
| German | frau | frow (as in "how") |
| Greek | yurń | ginay (g as in "gun") |
| Chinese | 太太 | tai tai (rhymes with "sky") |

How much do you depend on language? Imagine you are at a party and your hostess suggests a get-to-know-your-partner game — without words. You can come close to your partner and look at him, touch him, sniff him, use sign language — but you must not speak. You would quickly learn how limited your communication is. Other things you might realize are how seldom you usually touch other people, and how uncomfortable it is to be sniffed or to be stared at, at close range. Communication of this kind certainly involves feelings. It is also the way animals "talk" to one another.

## How do animals communicate?

When speaking to a friend you can tell him about such things as a recent holiday, your new home or what you plan to do tomorrow. An animal, such as a dog, cannot do this; it can only express feelings. Look at figure 19.2, which shows a dog expressing a feeling of aggression against an intruder. This reaction is probably due to fear; most animals behave aggressively when frightened. What is the feeling of the dog shown in figure 19.3?

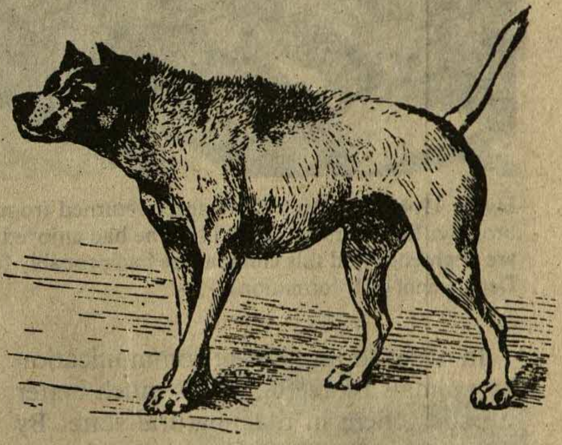


**Figure 19.2:** An aggressive dog.

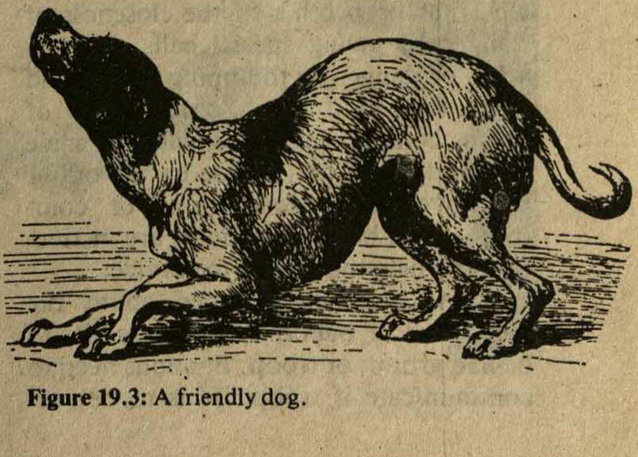


**Figure 19.3:** A friendly dog.

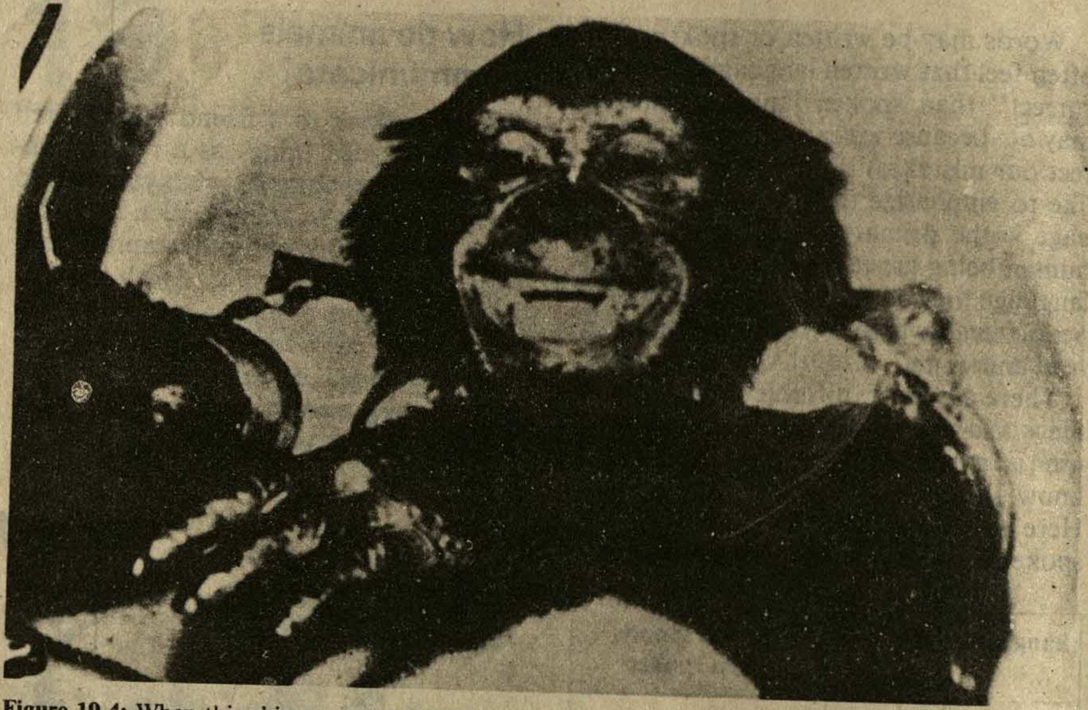


**Figure 19.4:** When this chimpanzee returned from a trip in an American space capsule, he was grinning broadly. Reporters concluded that he had enjoyed the experience. Actually, chimpanzees grin when they are frightened and this chimpanzee had probably found the trip terrifying. (Photo courtesy United States Department of Information)

In order to investigate communication by animals more fully, it is much better to study them in their natural state. By doing this it has been found out, for example, that bees can communicate by dancing. By dancing they are able to tell other bees where the best flowers are. Birds tell each other of the closeness of danger by giving special calls. Rabbits warn of danger by thumping the ground with their hind feet. Some species of moths communicate by smell. The male is able to find the female by the odour she gives off. Most forms of communication between animals are instinctive and help the species to survive.

A lot has been learned about the behaviour of baboons. Baboons like to be in a group, or troop. Baboons need to communicate if troop life is to be successful. A special bark from an alert baboon is all that is necessary to send the whole troop running from danger. A dominant male can stop two young baboons quarrelling by merely raising his eyebrows. Figure 19.5 shows how a baboon expresses three different feelings.

The way animals such as baboons express their feelings is not taught to them; it comes to them naturally. We say the behaviour is instinctive. A baboon gives its bark of alarm because it is frightened. It does this whether there are other baboons nearby or not. The bark, even though it alerts the others, is automatic. It is not intended as a message.

A baboon is unable to suppress its feelings or hide them by pretending to express other feelings. It cannot tell a lie as a human can.

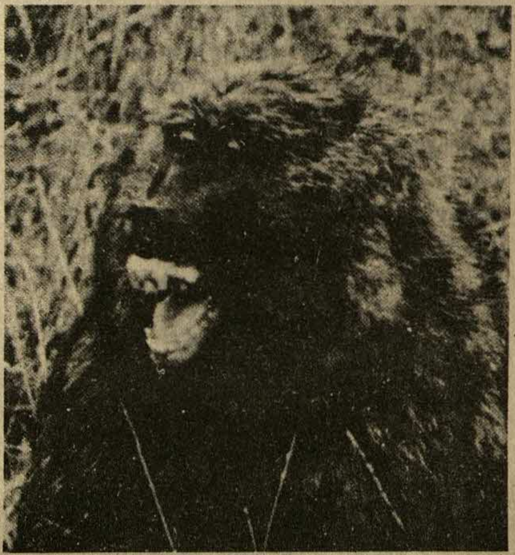


Figure 19.5a: A frightened baboon.

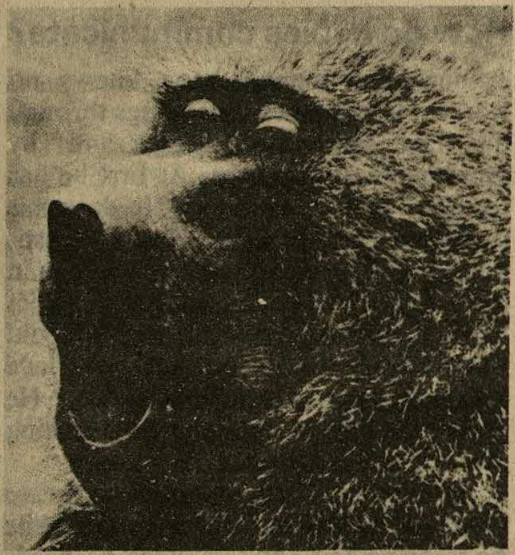


Figure 19.5b: A baboon unsure of itself.

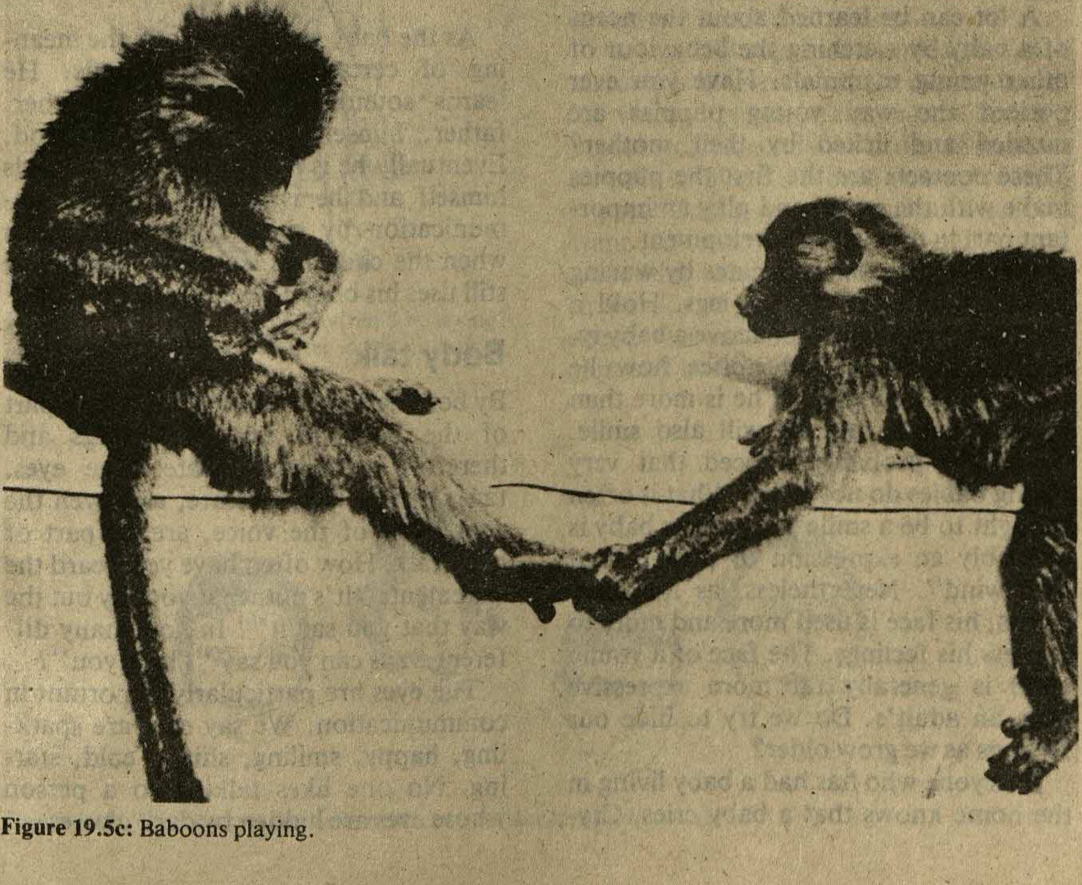


Figure 19.5c: Baboons playing.

## How do babies communicate?

A new-born human baby knows no words. He expresses his feelings through his face and by crying, and by movements of his limbs. At first he has to discover his own body. He does this by touch. He clenches his hands, grasps things, feels his body and puts things in his mouth. He also has a strong instinct to suck. Without this instinct he could not feed and would not survive. Have you ever watched a baby in his cot? He sucks his fingers, his toys or anything else in reach.

As he grows older he begins to notice his mother. This is particularly so while he is being fed. At this stage he needs response from his mother such as petting, cuddling and nuzzling.

A lot can be learned about the needs of a baby by watching the behaviour of other young mammals. Have you ever noticed the way young puppies are nuzzled and licked by their mother? These contacts are the first the puppies make with the world and play an important part in their early development.

A baby also communicates by waving his arms and kicking his legs. Hold a brightly coloured object above a baby lying on his back and notice how he responds in this way. If he is more than several months old he will also smile. You have probably noticed that very young babies do not smile. What is often thought to be a smile by a young baby is probably an expression of pain caused by "wind". Nevertheless, as the baby grows, his face is used more and more to express his feelings. The face of a young child is generally far more expressive than an adult's. Do we try to hide our feelings as we grow older?

Everyone who has had a baby living in the home knows that a baby cries. Crying at first is instinctive and expresses such feelings as pain, hunger and insecurity. The cry is the main way the baby has of attracting attention. However he soon learns to use it whenever he wants something. Parents learn too — they get to know when the baby is crying just to attract attention.

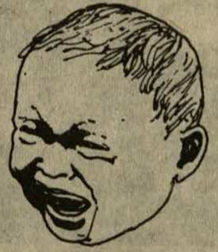


**Figure 19.6**

As the baby grows he learns the meaning of certain language sounds. He learns sounds that represent mother, father, himself, playthings and food. Eventually he is able to say these sounds himself and he is on the way to communication by speech. However, even when the child has learned to speak, he still uses his body to communicate.

## Body talk

By body talk we mean the use of any part of the body to express feelings and therefore to communicate. The eyes, face, hands, legs, posture, and even the expression of the voice, are all part of body talk. How often have you heard the statement: "It's not what you say but the way that you say it"? In how many different ways can you say "I hate you"?

The eyes are particularly important in communication. We say eyes are sparkling, happy, smiling, shifty, cold, staring. No one likes talking to a person whose eyes are hidden by dark glasses.

When talking with a person you like, you tend to look at the person more often than normal. If you are not interested in a person you tend to look at him less often. The eyes act as cues when two people are talking to one another. When the first person finishes his statement he tends to look at the second person as a signal for him to respond.

**Figure 19.7:** What might the boyfriend be saying? Do you think it would be better to say nothing at all?

The face also expresses feelings. Look at figure 19.8. It shows four different facial expressions. Notice how each expression is determined by the shape of the eyebrows, the position of the eyelids and the shape of the mouth.

The distance people stand from one another is another factor when communicating. You tend to stand close to a person you know, but further away from a stranger. Have you ever noticed a group of teenagers sitting on a lawn and talking among themselves? One couple, who obviously know one another very well, will sit very close together. Another person who is not well known to the group will tend to sit apart.

As any group communicates, each member will use words, the expression of his voice, his eyes, face, hands and the posture of his body in order to express himself to others. Would you agree with a psychologist who said that when we want to express how we feel about something our expression is 10 per cent in words, 40 per cent the way the words are spoken and 50 per cent facial expression and body gesture?

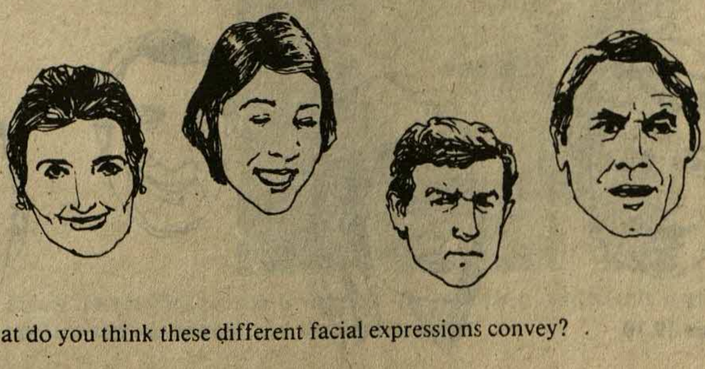


**Figure 19.8:** What do you think these different facial expressions convey?

**EXPERIMENT**

**19.1**

### *What do these signs mean?*

**What to do**

- Look at the eight signs in figure 19.9. These are internationally agreed road signs.

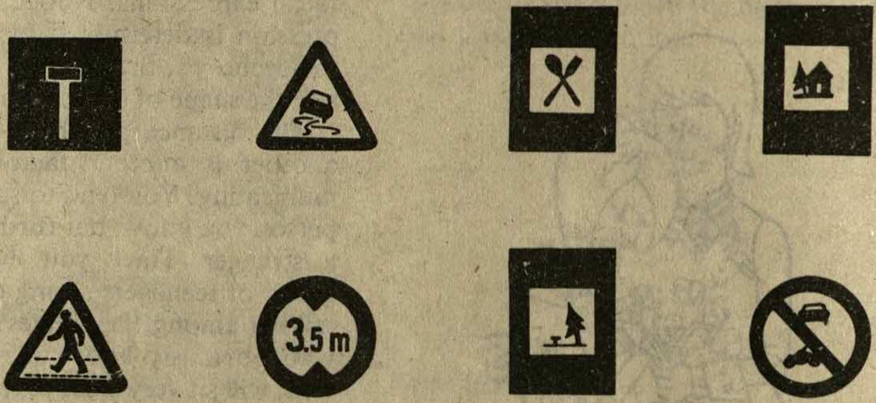


**Figure 19.9:** Some international road signs.

**Questions**

**19.1** What is the message each sign is designed to communicate?
**19.2** What is the advantage of using signs like these instead of words?
**19.3** Have you seen any other signs of this kind — not necessarily road signs? Draw some of them.

**EXPERIMENT**

**19.2**

### *Are there different kinds of smiles?*

**What to do**

- Look at the drawings in figure 19.10. These show four different kinds of smiles.

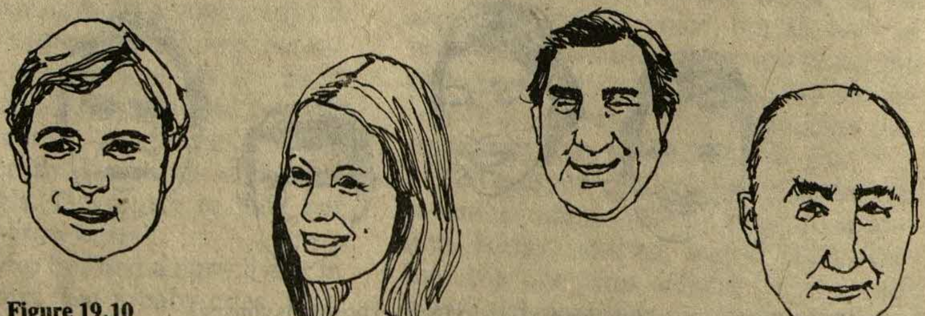


**Figure 19.10**

**Questions**

**19.4** Describe each kind of smile. Use words such as shy, cheeky, frightened, happy, polite, apologetic, amused, forced.

**19.5** Describe the shape of the mouth, the eyebrows and the position of the eyelids in each case.

EXPERIMENT 19.3

*What can a person's body talk tell us?*

**What to do**

- Use photos of people expressing their feelings. Select cuttings from newspapers or magazines or use photos you have taken.
- Paste each picture in your workbook. Near the picture write one sentence describing how you think the person feels. Then name and describe the part of the body (eyes, eyebrows, mouth, hands, etc.) that gives you the strongest clue. Figure 19.11 is given as an example.

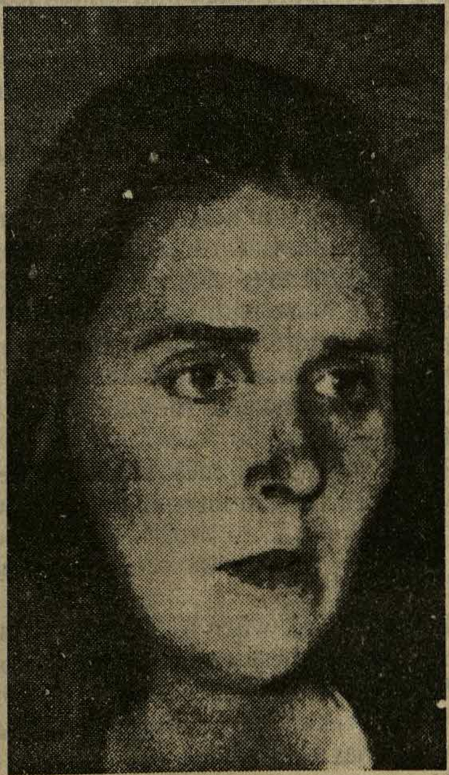


**Figure 19.11:** This person is worried. The strongest clue to this is given by the eyes, particularly the way the eyebrows are drawn down.

## Communicating

- We communicate by words and body talk.
- Animals other than humans can only express feelings; they cannot describe events or ideas. They cannot disguise their feelings.
- Animals, including humans, use many different parts of their bodies to express their feelings.

## Spelling list

aggressive
baboon
behaviour
communicate
facial
instinct
linguistics
posture
psychologist
response

## Things to do

**19.6** Do the colours black and white mean anything to you? Are fairies ever shown dressed in black? Are witches ever shown dressed in white? Try to find other examples of the use of black or white to convey particular feelings or messages.

**19.7** Do any sounds have a particular meaning to you, for example, an ambulance siren? Make a list for the home, school and the world outside.

**19.8** Do any pieces of music convey particular feelings to you such as (a) joy, (b) sadness, (c) dread or apprehension?

**19.9** Is it possible to teach a mouse to find its way through a maze? Make a simple maze with three false passages. Feed the mouse only by placing food at the end of the maze three times a day. Watch the mouse's behaviour and record the time it takes to find its way through the maze to the food. Does it eventually learn to avoid the false passages?

**19.10** If you have the chance, study puppies at play. Notice what they do with their tails, mouths and front paws.

## More questions

**19.11** Do you think when a cockatoo says "pretty cocky" it knows the meaning of these words? Give a reason for your answer.

**19.12** Have you ever heard puppies cry? Why do they cry?

**19.13** When does a lyrebird display its tail feathers? (R)

**19.14** Why does a cow "moo"?

**19.15** How can a baby show that he wants a toy that is tied up out of reach?

**19.16** Do you prefer to speak to a friend face-to-face rather than by phone? Explain.

**19.17** Imagine you are in a strange country and you cannot speak the language. Make up a short shopping list. Select a partner. Try, without words, to tell your partner what you want to buy and how much of each item you require.

**19.18** Birds, such as currawongs, pierce milk-bottle tops and drink some of the milk from the bottle. How do birds know to do this? Is this behaviour instinctive or is it learned by watching other birds? (R)

**19.19** What do you understand by the statement "He has allowed his heart to rule his head"?

## Test yourself (chapter 19)

In questions 1 to 4, choose the best answer and write its letter in your workbook.

1. Which of the following can best be communicated to another person by facial expression alone:
   (a) a picture of home
   (b) the idea that tomorrow is Saturday
   (c) a feeling of happiness
   (d) a picture of rain falling?
2. Which of the above can best be communicated by using the hands alone?
3. A rabbit when disturbed in the bush runs away thumping the ground with its hind feet. It does this
   (a) automatically, without thinking
   (b) because its hindquarters are much heavier than its forequarters
   (c) because it knows it has to warn other rabbits in the area
   (d) because it wants to frighten the aggressor.
4. Animals other than humans cannot lie (pretend to show feelings different from what they actually feel) because
   (a) they are unable to control their feelings
   (b) they have very little intelligence compared with humans
   (c) their behaviour is only instinctive
   (d) of all the above reasons.
5. Which of the four signs in figure 19.12 would you choose as an international road sign to tell motorists to stop?

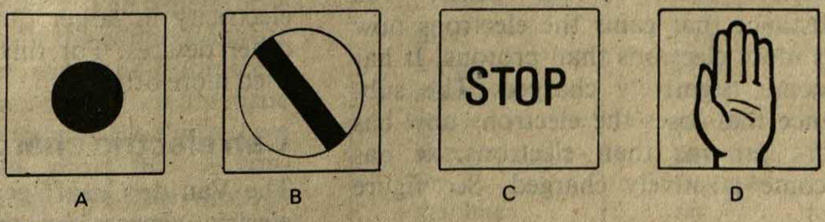


**Figure 19.12**

# 20

# Electricity

In chapter 8 we said that people have known about electricity for more than 2000 years. This early knowledge was of the kind of electricity that is produced by rubbing things together. No doubt you have had experience of electricity produced in this way. When pulling off a nylon shirt in dry weather you sometimes hear a crackling as it passes over your head. Stroking a cat can cause the same effect. Plastic ballpoint pens when rubbed also become electrified and will pick up small pieces of paper.

## Theory to explain electrification

Over the years there have been a number of theories proposed to explain electrification. In the theory used today (introduced in chapter 8), all atoms are believed to contain protons and electrons. Because most substances are normally uncharged, they must have equal numbers of protons and electrons.

Rubbing two substances together strips electrons off one substance and transfers them to the other. The substance that gains the electrons now has more electrons than protons. It has become negatively charged. The substance that loses the electrons now has more protons than electrons. It has become positively charged. See figure 20.1.

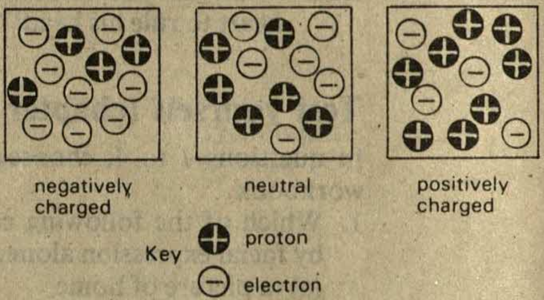


**Figure 20.1:** Explaining how an object can have an electric charge. If the object has more electrons than protons it is negatively charged. If it has more protons than electrons it is positively charged.

## Making electricity

Electricity is a form of energy. It can make things move — it moves the beaters in a cake mixer, and the electric train that takes us to work each day. Some other form of energy must be used to generate electricity. Table 20.1 lists some of the devices used to change energy of one form or another into electrical energy.

Batteries and dynamos can generate electricity in larger quantities than the other devices. For this reason they are used more often.

## Can electric charges travel?

The Van de Graaff generator produces electric charges by the friction of a

**Table 20.1:** Generating electricity

| Form of energy used | Device that converts this energy into electrical energy |
|---|---|
| chemical energy | battery |
| mechanical energy | dynamo |
| light energy | selenium cell |
| heat energy | thermocouple |
| mechanical energy | Van de Graaff generator |

plastic belt rubbing against a metal strip. The plastic belt is driven at high speed by an electric motor. This can be seen by removing the upper half of the large sphere of the generator, as shown in figure 20.2.

A second small sphere is connected to a water pipe and placed near the top of the generator. When the generator is set running, a large spark jumps across the space between the spheres. We say the electricity has jumped across the gap and flowed through the pipe to "earth". Electricity tends to flow to earth in the same way that creeks and rivers tend to flow into an ocean. It is impossible to change the level of the Pacific Ocean by emptying buckets of water into it. You can therefore understand that it is impossible to make the earth either negative or positive by using a Van de Graaff generator.

A fluorescent tube is now connected between the small sphere and the water pipe, as in figure 20.3. The generator is switched on again. If the connections are made with copper wire, the fluorescent tube flashes. If the connections are made with a plastic clothes line, the fluorescent tube doesn't flash. From this we conclude that electricity will flow through copper wire but not through a plastic clothes line. We say the copper wire is a conductor of electricity and the clothes line is a non-conductor, or insulator.

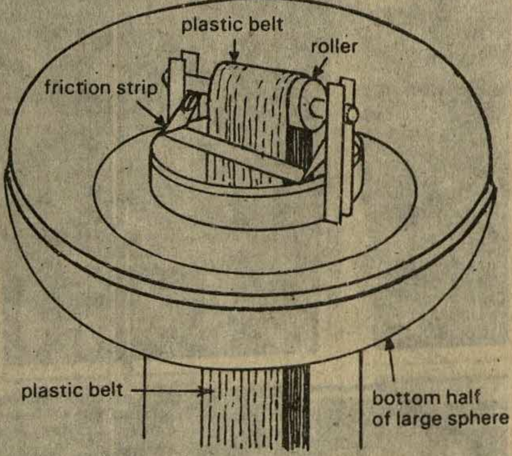


**Figure 20.2:** A Van de Graaff generator with the top half of the sphere removed to show the plastic belt and friction strip.

## Conductors and insulators

Figure 20.5 shows an easier way of finding out whether a material is a conductor or an insulator where electricity is concerned. If the material being tested conducts electricity, the lamp lights. It will not light if the material is an insulator. Table 20.2 lists some conductors and insulators.

**Table 20.2:** Conductors and insulators

| Conductors of electricity | Insulators against electricity |
|---|---|
| silver | nylon |
| copper | glass |
| aluminium | wood |
| brass | cotton |
| iron | porcelain |
| tin | perspex |
| graphite | air |

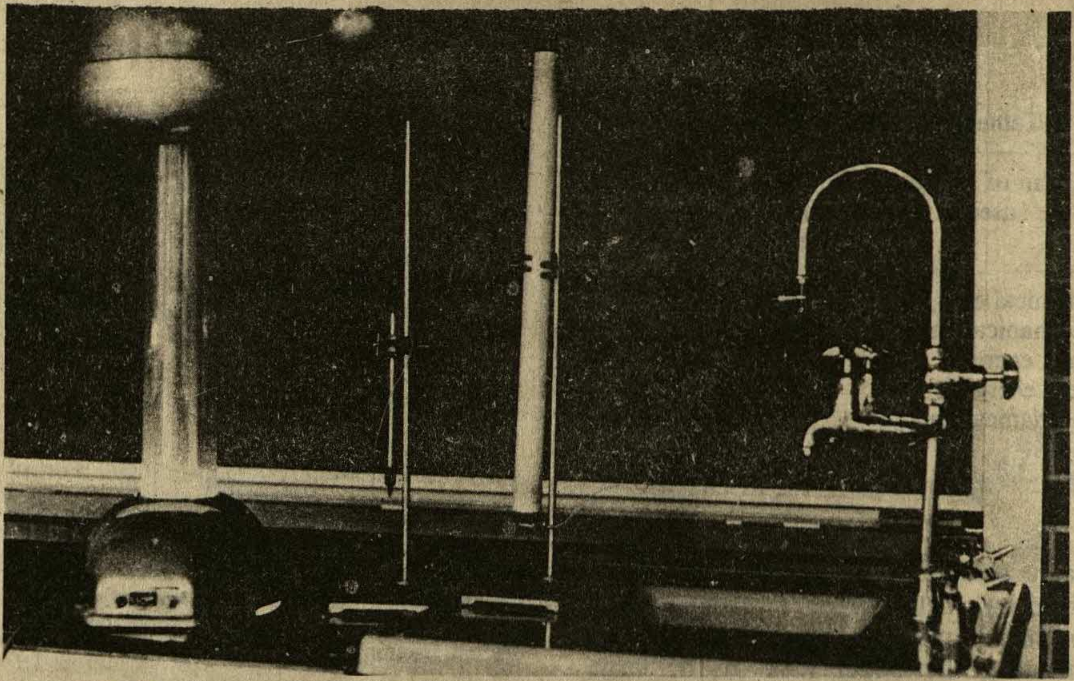


Figure 20.3: Electricity on the move. The charge jumps across from the generator to the small sphere. From there it flows through the metal conductors to the top end of the fluorescent tube. It then flows through the tube and out from the bottom end to earth (the water pipe). In the process of moving from the generator to earth the electrical energy is changed into sound, heat and light.

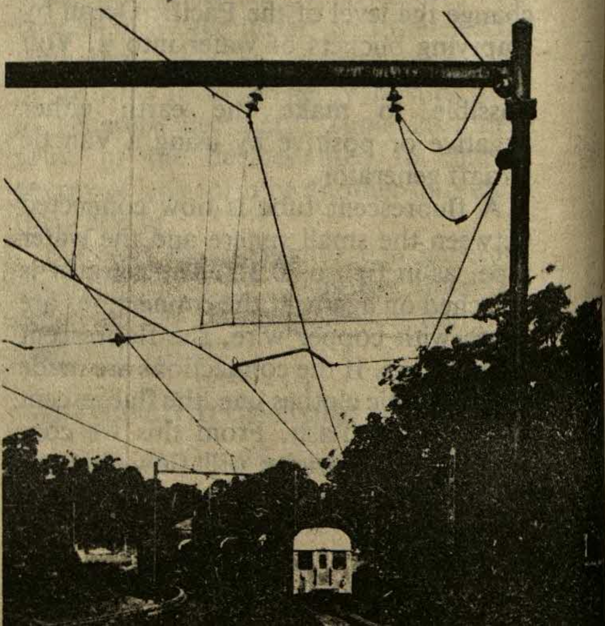
Notice that the conductors are all metals, with the exception of graphite. Graphite is a form of carbon. It is used in pencils, mixed with clay, and is the centre rod in most dry cells.

The insulators are all non-metals.

***Do all metals conduct electricity equally well?*** This can be answered by again using the apparatus shown in figure 20.5. This time, however, we test long thin pieces of metal. If we use a long thin piece of iron wire we find the lamp does not glow as brightly as with a similar piece of thin copper wire. We say that the iron offers more resistance to the flow of electricity than the copper.

***Is the human body a conductor?*** The human body is a conductor of electricity — but not a very good one. Therefore a small voltage has no noticeable effect on the body. However, if a person touches a bare wire from the 240 volt mains, sufficient current can be forced through the

**Figure 20.4:** How does the electricity flow when electric motors are pulling a train? The overhead wire is highly charged — hence the insulators to prevent the electricity from escaping to earth. When the driver of the train turns a switch to the "on" position, electricity flows from the overhead wires through the motors to the rails. The rails are "earth" in this particular circuit.



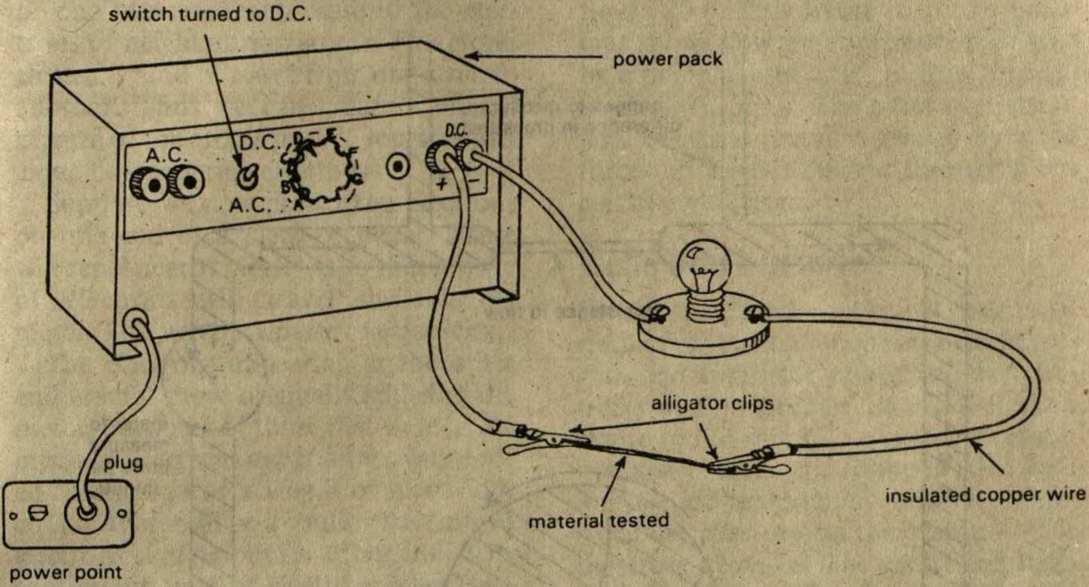


**Figure 20.5:** Testing materials to see whether they conduct electricity. In this apparatus the electricity comes through a power pack. If the material being tested is a conductor, the bulb lights. If the material is an insulator or a very poor conductor, the bulb does not light.

body to cause shock. If the current passes through the heart, it can stop it beating. In this case, unless quick action is taken (artificial respiration), death will result within five minutes.

## The volt — the unit of electrical pressure

When testing conductors and insulators we used a simple electric circuit. It is called a circuit because it provides a path for the electrons.

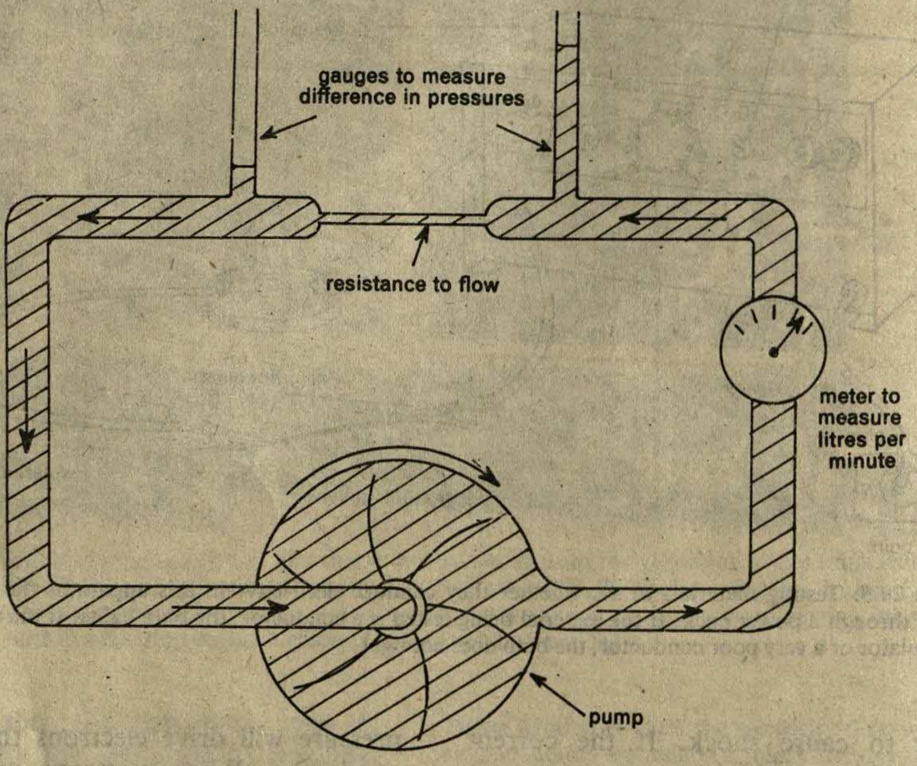
Power packs, batteries and dynamos force electrons from one point in a circuit and pile them up at another point. But electrons repel one another, so to move more and more electrons in the one direction requires a force. In the circuit shown in figure 20.5 this force was provided by the power pack.

Pushing electrons together creates a kind of electrical pressure. Electrical pressure will drive electrons through a conductor. When electrons are under pressure they have potential energy or, as it is sometimes called, electrical potential. The unit of electrical pressure or potential is the *volt* (V).

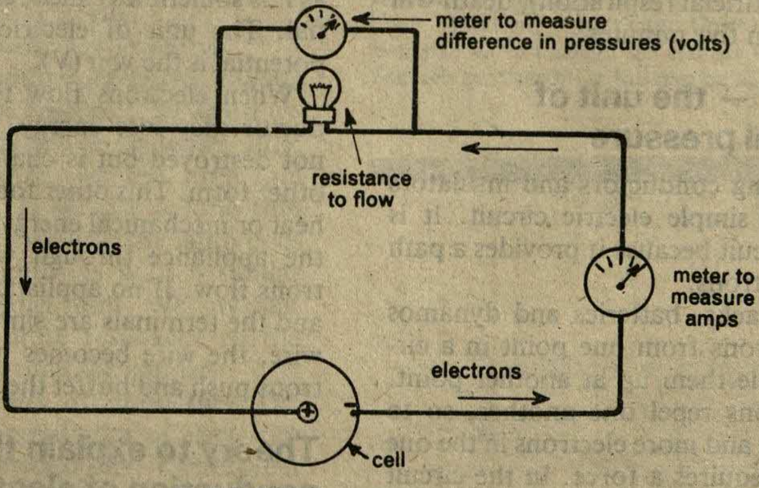
When electrons flow through a conductor they lose energy. This energy is not destroyed but is changed into some other form. This other form can be light, heat or mechanical energy, depending on the appliance through which the electrons flow. If no appliance is being used and the terminals are simply joined by a wire, the wire becomes hot as the electrons push and buffet the atoms in it.

## Theory to explain the conduction of electricity

Metals are good conductors of electricity. The atoms in metals are packed close together. This means that the electrons



THE WATER CIRCUIT



THE ELECTRICAL CIRCUIT

**Figure 20.6:** Comparing the flow of water to the flow of electricity. An increase in water pressure causes more litres to flow per minute; an increase in electrical pressure causes an increase in amps.

of one atom are very close to the electrons of neighbouring atoms. Therefore, electrons tend to move from one atom to another. Thus we can create a mental picture of the atoms packed together in a cloud of wandering electrons.

Suppose we now place extra electrons on one end of a piece of metal. These will repel nearby electrons so that a wave of electrons will travel through the metal. This wave is a pulse of electricity.

The electrons appearing at the other end are not those originally added to the metal, but some of those that were in the metal. If electrons are continuously added to one end of a length of metal in a circuit, there will be a continuous flow of electrons coming out the other end. This continuous flow of electrons is an electric current.

## The amp — the unit of current

Quite often we need to know how fast electricity is flowing in a circuit. We could measure this rate of flow — or current — if we could count the number of electrons passing a given point in a circuit per second. But one electron per second is an extremely small current — such a unit is far too small for practical use. A very much larger unit is therefore used. This is called the *ampere*, or *amp* for short.

1 amp = 6 250 000 000 000 000 000 electrons per second
= $625 \times 10^{16}$ electrons per second

A household toaster uses about 4 amps of current. This means that

4 × 6 250 000 000 000 000 000 electrons

flow through the toaster per second.

The way voltmeters and ammeters (instruments to measure volts and amps) are connected in a circuit is shown in figure 20.6. This figure is in two parts. One shows how water pressure produced by a pump causes water to flow through a circuit of pipes. The other part shows how electrical pressure created by a cell forces an electric current through a circuit of conductors.

## Cells and batteries

Electrical cells are convenient sources of electricity. The common cell used in torches and transistor radios delivers electricity at a pressure of 1.5 volts. It has a centre rod of graphite and a zinc casing. The space within the casing is filled with a paste of ammonium chloride. Electrons are piled up on the casing — it is therefore negative. The centre rod loses electrons — it is therefore positive. See figure 20.7.

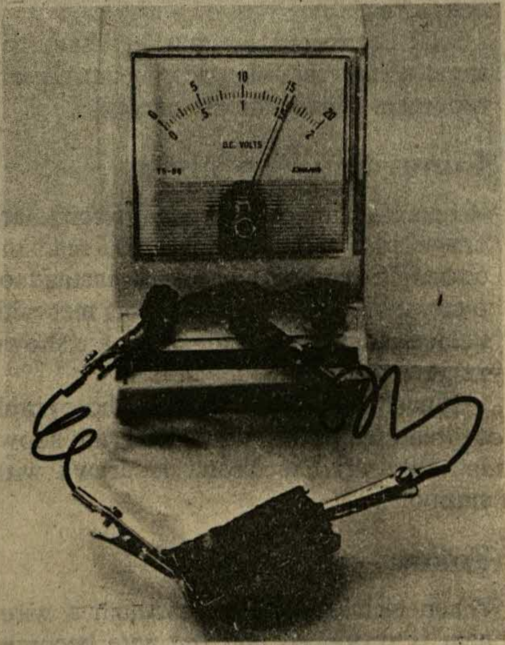


**Figure 20.7:** A dry cell with a section cut away. Notice that the cell still registers 1.5 volts although it would not deliver as much energy as an undamaged one.

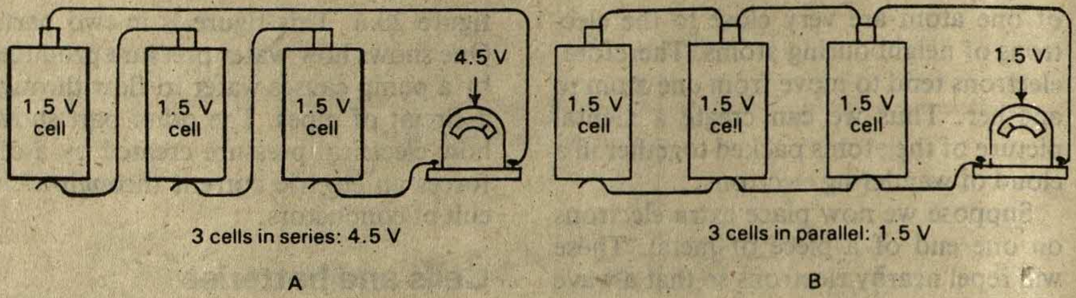


**Figure 20.8:** Three cells connected in series (A) and in parallel (B).

The size of the cell makes no difference to the voltage — a small cell has the same voltage as a large one. But a small cell does not contain as much electrical energy as a large one and therefore will be exhausted more quickly.

If a voltage higher than 1.5 volts is needed, a battery of cells must be used. When cells are used to increase the voltage they must be connected in series. See figure 20.8.

Cells connected in parallel have the same voltage as a single cell but the arrangement delivers more energy.

## Some circuit symbols

When diagrams of electrical circuits are drawn it is easier to draw and read the circuits if symbols are used instead of pictures. A few of the symbols met with in elementary circuit diagrams are shown in figure 20.9.

Figure 20.10 consists of a photograph of a simple circuit and a diagram showing the way the circuit is drawn with symbols.

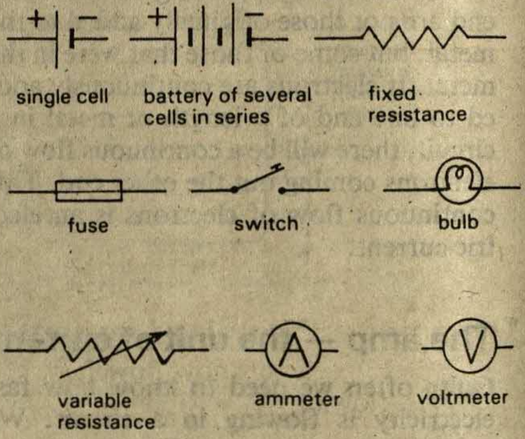


**Figure 20.9:** Some circuit symbols.

## Fuses

When electricity flows through a wire, heat is produced and the wire becomes warm — especially if it offers any great resistance to the current. The more electricity is flowing through the wire the hotter it becomes.

If too strong a current flows in the electrical wiring of a house, for example, enough heat may be produced to cause a fire or damage the wiring severely. Fuses are used to prevent this from happening ("fuse" means to melt). A fuse is a short piece of very thin wire in a porcelain holder or glass tube. (See figure 20.11.)

Fuse wire is much thinner than that used in the circuit wiring of a home or factory. Being thin it offers more resistance than the thicker wire. When the current flowing through the circuit exceeds the maximum safe current, sufficient heat is produced to melt the fuse. This stops the current before any damage is done.

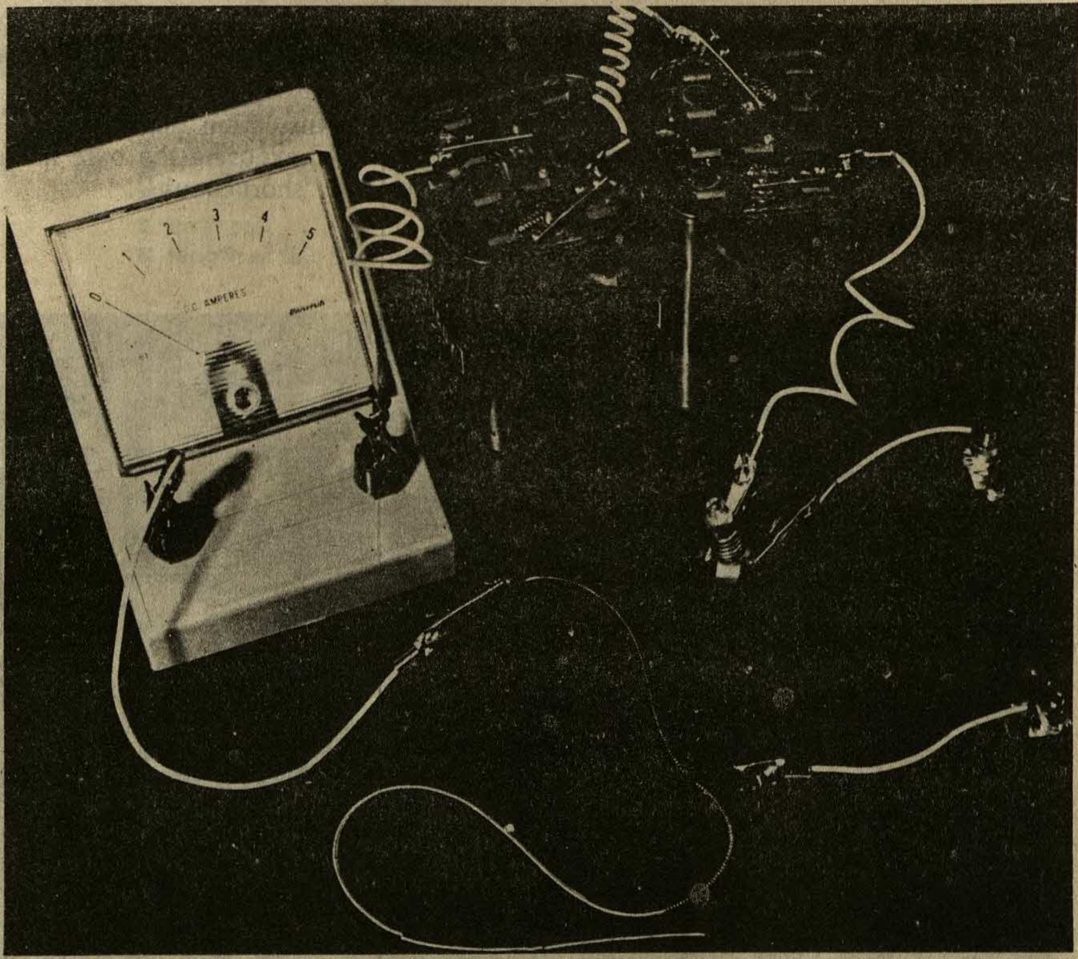
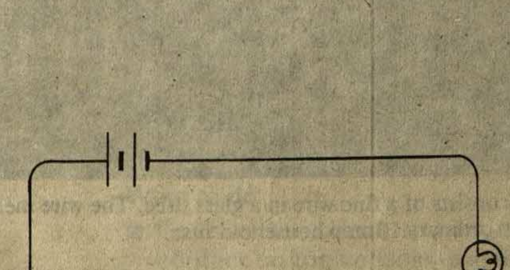


**Figure 20.10:** Photo of a simple electrical circuit (A) and the diagram representing it (B).



Many homes have circuit-breakers instead of fuses. These contain a spring and a bimetal strip. Excessive current heats the bimetal strip, causing it to bend. This releases the spring and breaks the circuit.

Excessive currents may be caused by connecting too many appliances, such as radiators, to the same circuit. Excessive currents will also flow if, for example, some of the insulation on the wires is worn through, exposing the bare metal and causing a "short circuit".

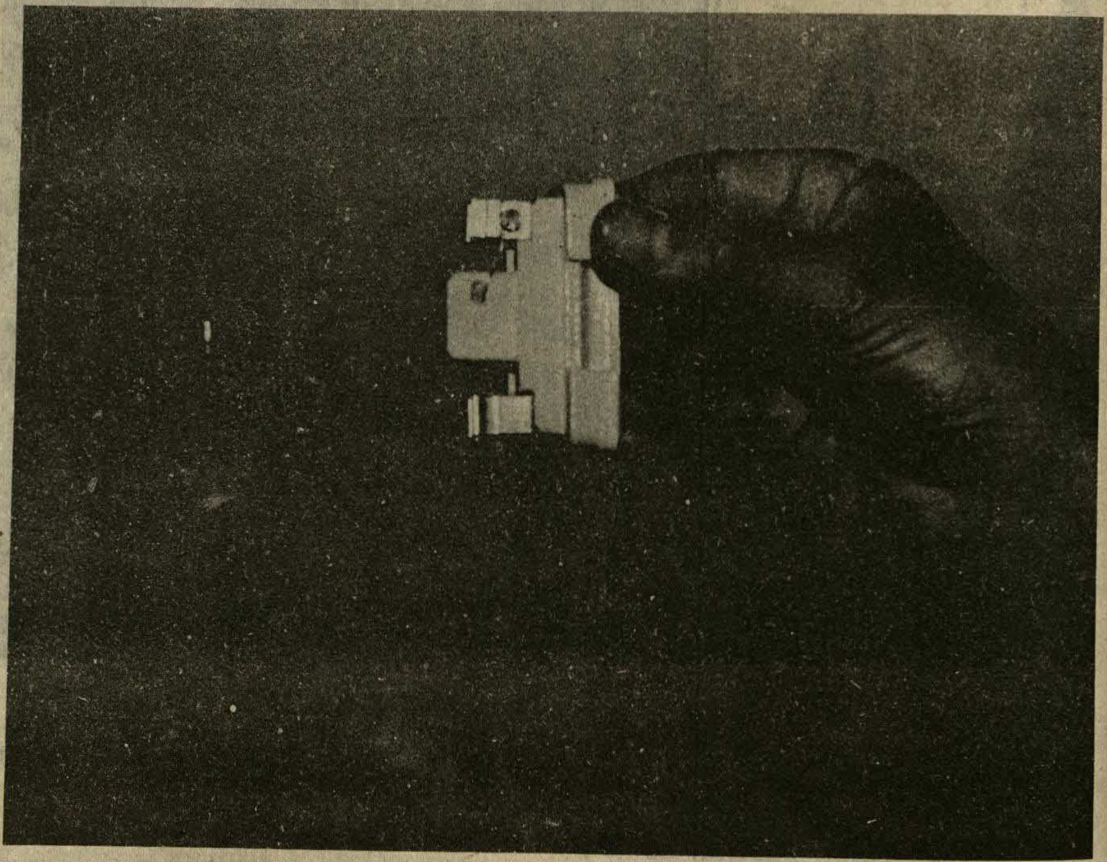


**Figure 20.11:** Two types of fuses. The one on the left consists of a fine wire in a glass tube. The wire melts if the current exceeds 2 amps. The one on the right is an ordinary 10 amp household fuse.

EXPERIMENT 20.1

*How much current is needed to melt a piece of fine fuse wire?*

**Each group will need:**

- insulated connecting wire
- variable resistance, or replacement jug element and two alligator clips
- three dry cells or power pack
- switch
- ammeter
- length of fine fuse wire (2 amp) or small piece of steel wool

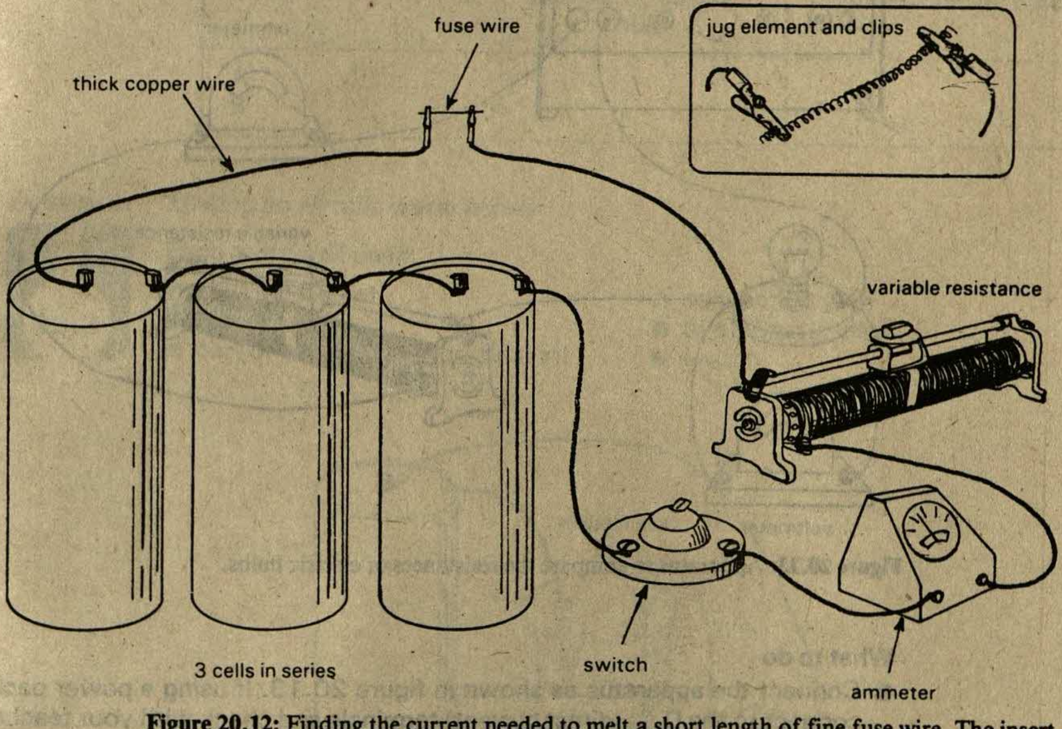


**Figure 20.12:** Finding the current needed to melt a short length of fine fuse wire. The insert shows how to use a length of jug element and two alligator clips instead of the variable resistance shown.

**What to do**

- Connect the circuit shown in figure 20.12, making sure that the sliding contact on the variable resistance is at the end away from the connecting wires.
- Attach a length of fine fuse wire across the ends of the thick copper wire, as shown in figure 20.12. If fine fuse wire is unavailable, a thin length of steel wool would be a suitable alternative.
- Turn on the switch and slowly increase the current by moving the slide along the variable resistance or by bringing the two alligator clips closer together on the element.
- Read the ammeter immediately before the wire melts. Record the current.

**EXPERIMENT**

**20.2**

## *Comparing the resistance of two six volt bulbs*

**Each group will need:**

- power pack or 6 volt battery
- two different 6 volt bulbs
- bulb socket
- switch
- connecting wire
- variable resistance
- ammeter
- voltmeter

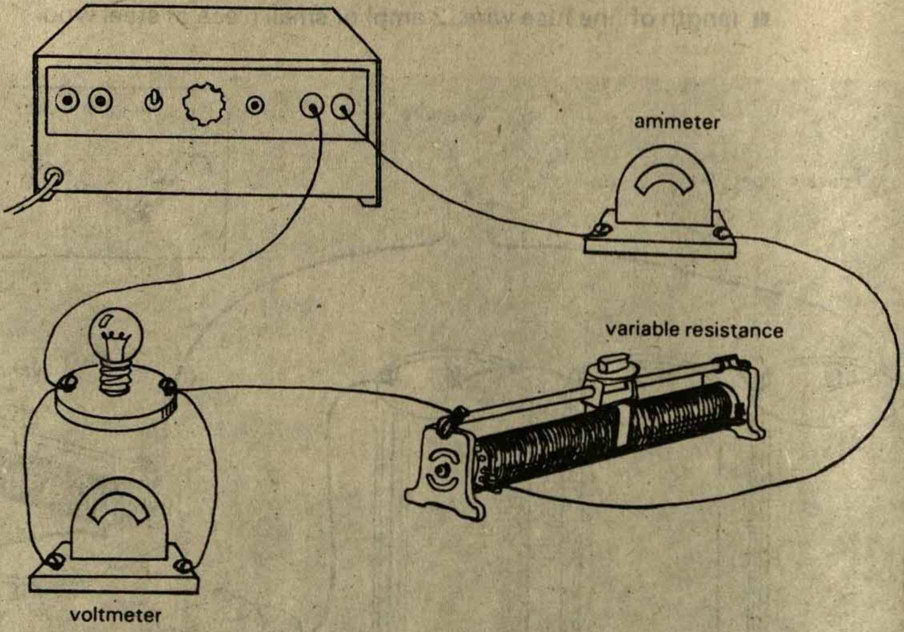


**Figure 20.13:** Apparatus to compare the resistances of electric bulbs.

### What to do

- Connect the apparatus as shown in figure 20.13. If using a power pack, connect to the D.C. (direct current) terminals and check with your teacher that the dial is at the correct setting for the type of bulb used.
- Fit bulb A in the socket and switch on the current.
- Move the slide along the variable resistance until the voltmeter reads 6 volts.
- Read the ammeter.
- Switch off the power, change bulbs and switch on again.
- Adjust the variable resistance again to give a reading of 6 volts on the voltmeter.
- Read the ammeter and note whether bulb B is duller or brighter than bulb A.
- Switch off the power.

### Questions

**20.1** Which bulb gave out more light, A or B?

20.2 Which bulb had the greater current passing through it? What is the connection between light produced and current flowing? (Remember the voltage is 6 volts in both cases).

20.3 Which bulb offered the greater resistance to the flow of electricity?

- Switch on the power again and move the slide slowly to the far end of the variable resistance. Read the meters at three positions of the slide and note the brightness of the bulb each time. Switch off. Record your results as follows:

| Voltage across the bulb | Current through the bulb | Brightness of the bulb |
|---|---|---|
| A | | |
| B | | |

**EXPERIMENT**

**20.3**

## *Making an electric water heater*

**Each group will need:**

- 100 mL beaker
- one dry cell
- part of replacement jug element
- connecting wire
- two alligator clips
- switch

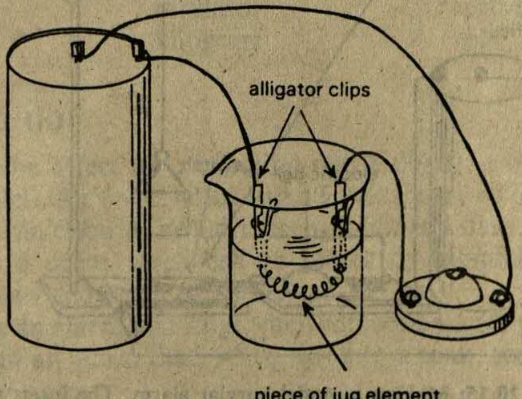


**Figure 20.14:** Making an electric water heater.

### What to do

- Straighten the jug element and cut off about 20 cm. Wind it into a spiral on a pencil.
- Connect the circuit as shown in figure 20.14. Use the alligator clips to connect the ends of the jug element.
- Pour enough water into the beaker to just cover the jug element.
- Close the switch for two minutes.

**Question**

**20.4** Did the water become warm? Did any of the connecting wires become warm? If they did not, explain why.

**EXPERIMENT 20.4**

### *Making a burglar alarm*

**Each group will need:**

- two dry cells (if torch cells are used you will need alligator clips to make connections)
- connecting wire
- retort stand and clamp
- kilogram weight
- electric bell
- fine black cotton
- two paper binders
- piece of cardboard

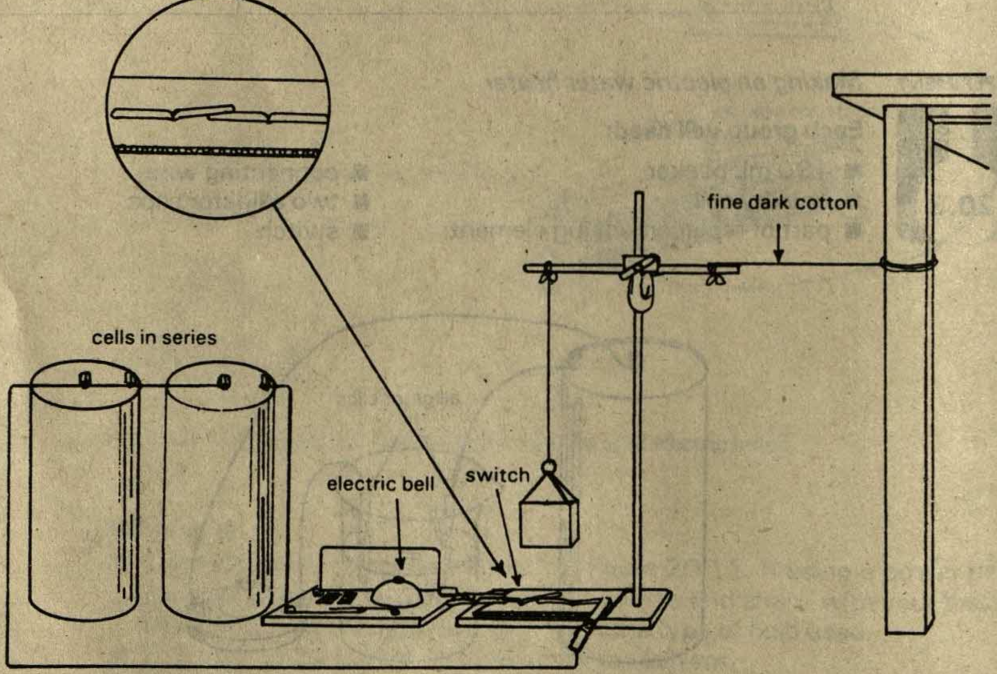


**Figure 20.15:** Making a model burglar alarm. The insert shows how the switch is made from two paper binders and a piece of cardboard.

**What to do**

- Make your switch using two paper binders pushed through a piece of cardboard, as shown in figure 20.15.
- Connect the circuit as shown in the figure. Test it to find out whether the bell rings when the weight drops on to the switch. You may have to rest a small piece of wood on the switch to force it to close when the weight drops.
- Try it out on your friends (in fun).

## Electricity

- A negative charge is caused by a surplus of electrons.
- A positive charge is caused by a shortage of electrons.
- Like charges repel. Unlike charges attract.
- Solid conductors are made up of closely packed atoms surrounded by a cloud of loosely held electrons.
- An electric current is a flow of electrons in a conductor.
- The volt is the unit of electrical pressure. The amp is the unit of current.
- The greater the voltage, the greater the current driven through a conductor.

## Spelling list

alarm
alligator
ammeter
amp
appliance
battery
burglar
circuit
conductor
current
fluorescent
fuse
generator
graphite
insulator
kilogram
parallel
porcelain
resistance
series
spiral
symbol
variable
volt

## Things to do

**20.5** Test the effect of connecting two bulbs first in series and then in parallel. Use 6 volt bulbs and a 6 volt source of power.

**20.6** Make an electric fire alarm using a bimetal strip.

**20.7** Take a spent torch cell to pieces to examine the parts. Use a hacksaw and a pair of pliers.

**20.8** Make an alarm that rings when someone stands on a mat.

**20.9** Design an alarm that, when fitted to a tank, rings when the tank is full of water.

**20.10** Design an alarm that rings when the postman puts a letter in your letter box.

**20.11** Look up the procedure for treatment of electric shock. Practise the procedure. (R)

## More questions

**20.12** List ten conductors and ten insulators.

**20.13** What are atoms composed of? What do you know about the particles within the atom?

**20.14** A piece of plastic is charged negatively by rubbing with cloth. Explain how this happens.

**20.15** Explain how an electric current can flow through a piece of metal.

**20.16** Why do overhead power lines have thick wire?

**20.17** What is the unit of electric current?

**20.18** What is the unit of electrical pressure?

**20.19** Many areas in America have 110 V electrical supply; Australia uses 240 V. What would happen if one of our toasters was connected to an American supply? What would happen if one of their toasters was connected to our supply?

**20.20** What would happen to the resistance of a replacement jug element if:

(a) only half of it was used in the jug?

(b) the element was stretched out, bent back in the middle to make a double wire, made into a new spiral and connected as a double wire in the jug?

(c) Would the water take a longer or a shorter time than normal to boil in (a)? In (b)? (See appendix 1.)

**20.21** Is a set of small Christmas tree lights connected in series or parallel? How would you find out? (See appendix 1.)

**20.22** An electrical storm is the result of clouds becoming charged with electricity. Can you suggest a theory to explain how clouds become charged in this way?

**20.23** Sometimes when a cat is frightened its fur bristles. The following theory is suggested to explain this. Fright causes a flow of electricity into the hairs of the cat. Being charged with the one kind of electricity, the hairs repel each other and therefore stand up.

What would you do to test this theory?

## Test yourself (chapter 20)

Write the answers to questions 1 to 8 in your workbook.

1. Name the type of energy that is converted to electrical energy in a car battery.
2. An object with a negative charge of electricity must have more (a) ______ than (b) ______.
3. Copper is a (a) ______ of electricity whereas paper is an (b) ______.
4. Electrical pressure is measured in ______.
5. Rate of flow of electricity is measured in ______.
6. Thick wires offer ______ resistance to the flow of electricity than thin wires of the same metal.
7. Copper is a ______ conductor of electricity than iron.
8. Into what form of energy is electricity changed in a fuse wire?

Choose the best answer to each of the questions 9 to 14 and write its letter in your workbook.

9. Which of the following groups of materials contains only conductors?
   - (a) copper, zinc, glass, graphite
   - (b) copper, lead, gold, graphite
   - (c) zinc, porcelain, glass, wood
   - (d) glass, wood, quartz, porcelain.
10. Which group in question 9 contains only insulators?

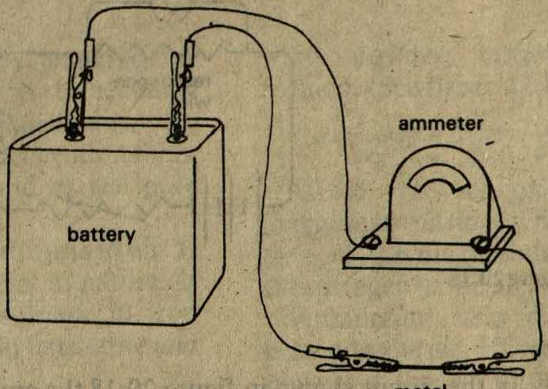


**Figure 20.16**

11. The current shown by the ammeter in figure 20.16 would be increased if the piece of metal held between the two clips was
    - (a) thinner
    - (b) thicker
    - (c) longer
    - (d) bent.

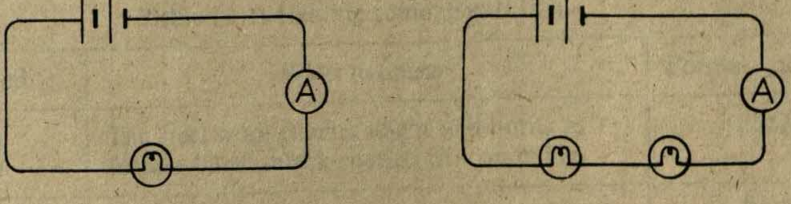


**Figure 20.17**

12. The circuit diagrams in figure 20.17 use similar batteries and bulbs. Compared with circuit A, the two bulbs in B will be
    - (a) brighter and the ammeter reading will be greater than in A
    - (b) duller and the ammeter reading will be less than in A
    - (c) brighter and the ammeter reading will be the same as in A
    - (d) duller and the ammeter reading will be the same as in A.

13. When a hot-water jug is switched on, the element in the jug becomes hot but the connecting lead from the power point remains cool. This happens because, compared with the connecting lead
    (a) the element is shorter
    (b) the element is thinner
    (c) the element has more resistance than the connecting lead
    (d) the element has less resistance than the connecting lead.

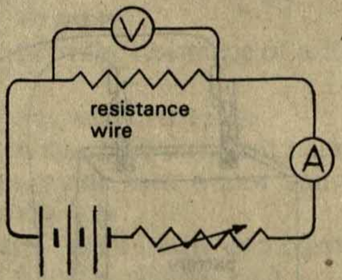


**Figure 20.18**

14. In the circuit shown in figure 20.18 the ammeter measures the current flowing through the piece of resistance wire and the voltmeter measures the voltage drop across it. Four pieces of resistance wire are tested separately in the circuit. The wire with the greatest resistance would show
    (a) an ammeter reading of 4 and a voltmeter reading of 8
    (b) an ammeter reading of 8 and a voltmeter reading of 4
    (c) an ammeter reading of 4 and a voltmeter reading of 4
    (d) an ammeter reading of 10 and a voltmeter reading of 10.

# 21

# The activity series of metals

Gold has been valued by mankind for thousands of years. It is a beautiful metal, easily beaten or shaped; above all, it does not tarnish: it reacts with neither air nor water. It is found as the pure metal in rocks and gravel.

Iron, on the other hand, rusts in air. It is never found as the metal in nature. It occurs combined with sulphur in iron pyrites and with oxygen in haematite and magnetite.

In this chapter we shall compare the activities of a number of metals by examining their reactions with other substances.

## Reactions when heated in air

Magnesium ribbon when heated in air burns with a brilliant white flame. A white powder, magnesium oxide, is formed. (See figure 21.1.)

$$\begin{array}{ccccc} \text{magnesium} & + & \text{oxygen} & \rightarrow & \text{magnesium oxide} \\ 2Mg & + & O_2 & \rightarrow & 2MgO \end{array}$$

Mixed with the oxide are traces of magnesium nitride. This is formed by a little of the magnesium combining with the nitrogen in the air.

Aluminium strip does not ignite if heated in the air. However, if aluminium powder is thrown into a flame it ignites like a flashlight. Aluminium is a very active metal, particularly when finely divided. A finely divided substance is more likely to react because it has a much greater surface area than a lump of the same substance.

Table 21.1 sets out the results of heating some other metals in air.

**Table 21.1:** Heating some metals in air

| Metal heated | What happens | Formula of oxide |
|---|---|---|
| Steel wool in burner flame | The steel wool catches alight and burns to form a bluish-black coating of iron oxide. | $Fe_3O_4$ |
| Lead strip in a crucible lid | The lead melts. If heated for some time and cooled, a yellow powder is seen on the metal. This is lead oxide. | PbO |
| Copper strip in burner flame | The copper becomes red hot. The flame is coloured green. When cool the metal is found to be covered by a black layer of copper oxide. | CuO |

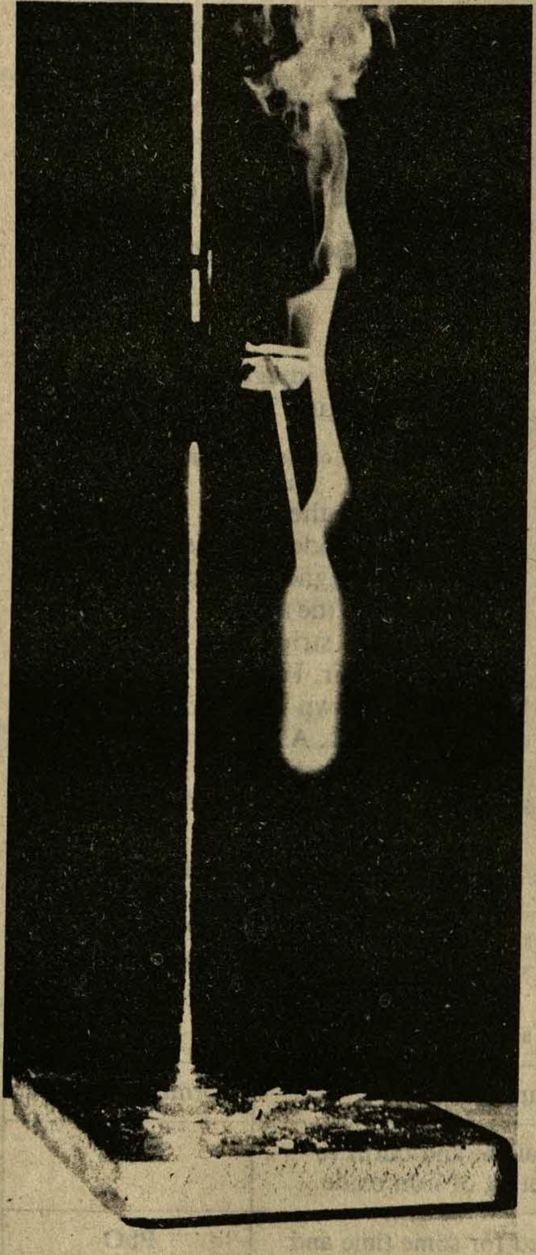


**Figure 21.1:** Magnesium ribbon burning in air to form magnesium oxide. Some of the oxide is in the form of smoke seen above the flame but most of it is on the base of the stand below the flame.

No change is noticed when gold is heated in air and allowed to cool. Gold does not form an oxide.

These results do not enable us to place the metals in the order of their activity in burning. This is so because the metals were not all in the same condition. The aluminium was powdered, the iron was in the form of fine wire and the others were in strips. Also, the oxide on the surface of some metals prevents air from getting to the metal underneath. If it were possible to have uniform conditions for all the metals we would find the order of activity to be magnesium, aluminium, iron, lead, copper and gold.

## Reactions with cold water

Not many metals react quickly when brought in contact with cold water. However, many show some corrosion if left in contact with water for several weeks. Air generally plays a part in this type of corrosion. Iron, for example, will not rust in water from which the air has been removed by boiling. (See figure 21.2.)

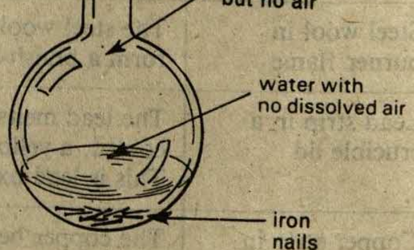


**Figure 21.2:** Iron will not rust if air is absent. The air has been driven out of the flask by boiling the water for several minutes and sealing the flask before the steam condenses.

There are some metals that react readily with cold water. Examples of these are potassium, sodium and calcium.

Sodium is a remarkable metal. It floats on water and can be cut with a knife. When a small piece is dropped on to water it reacts violently, liberating the gas hydrogen and forming an alkaline solution:

$$\text{sodium} + \text{water} \rightarrow \text{sodium hydroxide} + \text{hydrogen}$$
$$2Na + 2H_2O \rightarrow 2NaOH + H_2\uparrow .$$

Calcium reacts in the same way as sodium but much more slowly. (See figure 21.3.)

Magnesium will react only if it is powdered, and then very slowly. Metals such as aluminium, iron, zinc, lead and copper have no immediate reaction with cold water.

From these results we can place three metals in the order of their chemical activity with cold water. The metals, in order, are sodium, calcium and magnesium.

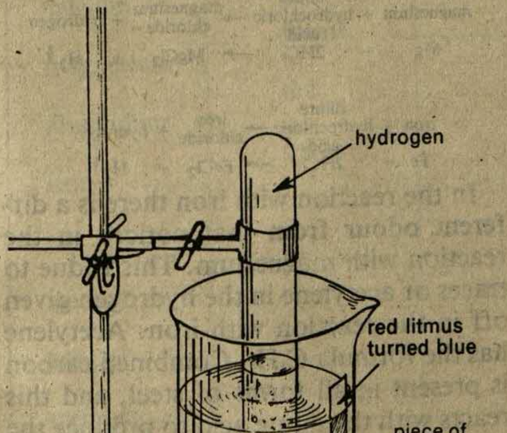


**Figure 21.3:** The reaction between water and calcium. Bubbles of hydrogen are liberated and a solution of calcium hydroxide is formed.

## Reactions when heated in steam

Pairs of substances that will not react when cold, often do so when mixed and heated. A theory to explain this states that heating causes the minute particles within the substances to move more violently. Therefore, when they collide there is a greater chance of their combining.

Magnesium shows this effect in its reaction with water. This metal reacts very slowly with water but much more rapidly when heated in steam. Figure 21.4 shows how the heating may be carried out.

Figure 21.5 shows apparatus that may be used to demonstrate that hot iron reacts with steam. However, even under these conditions, the reaction is still very slow.

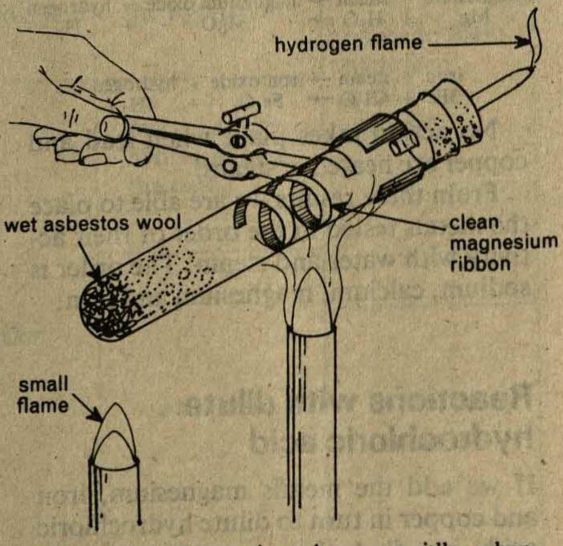


**Figure 21.4:** Magnesium burns rapidly when heated in steam. The water in the asbestos wool is brought to the boil and then the magnesium is heated strongly. The reaction is exothermic, so that once started the magnesium needs no further heating.

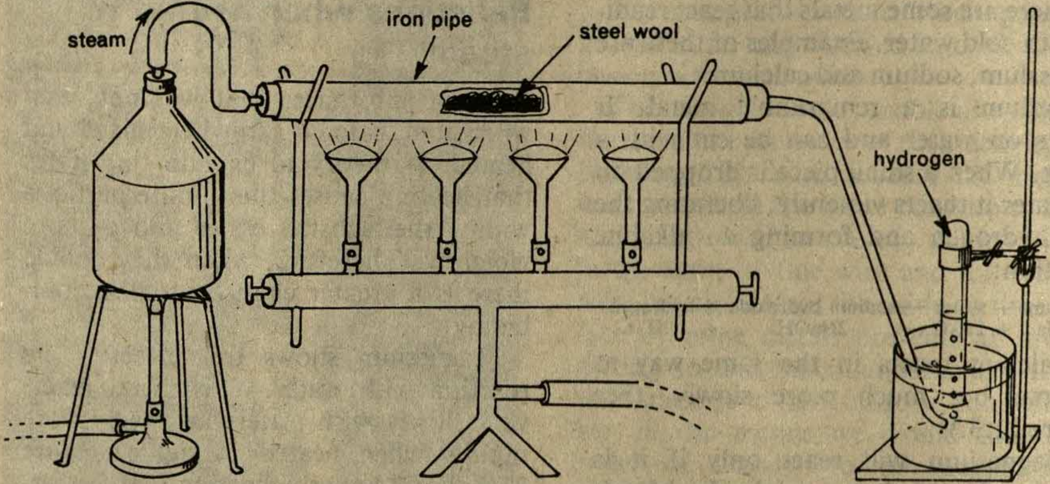


**Figure 21.5:** Steel wool burns slowly when heated in steam, to form iron oxide and hydrogen.

The equations for the reactions of magnesium and iron with water are as follows.

magnesium + steam → magnesium oxide + hydrogen
$Mg + H_2O \rightarrow MgO + H_2$

iron + steam → iron oxide + hydrogen
$3Fe + 4H_2O \rightarrow Fe_3O_4 + 4H_2\uparrow$

No action takes place when lead and copper are heated in steam.

From these results we are able to place the metals tested in the order of their activity with water and steam. The order is sodium, calcium, magnesium and iron.

## Reactions with dilute hydrochloric acid

If we add the metals magnesium, iron and copper in turn to dilute hydrochloric acid, we find that magnesium reacts violently, iron slowly and copper not at all. This means that we can place the metals in the same order of activity as we placed them earlier, that is, magnesium, iron and copper.

The gas hydrogen is liberated in the reactions with magnesium and iron. The equations are as follows:

magnesium + dilute hydrochloric acid → magnesium chloride + hydrogen
$Mg + 2HCl \rightarrow MgCl_2 + H_2\uparrow$

iron + dilute hydrochloric acid → iron chloride + hydrogen
$Fe + 2HCl \rightarrow FeCl_2 + H_2\uparrow$

In the reaction with iron there is a different odour from that noticed in the reaction with magnesium. This is due to traces of acetylene in the hydrogen given off in the reaction with iron. Acetylene has the formula $C_2H_2$. Combined carbon is present in all forms of steel, and this reacts with the dilute acid to produce the acetylene.

An unexpected result is obtained when aluminium is added to dilute hydrochloric acid. Since aluminium is high on the activity list we would expect it to act about as violently as magnesium. Instead, it does not react until about half an hour has elapsed. The process can be speeded up by using concentrated acid. In this case, nothing happens for about three minutes and then there is a violent effervescence of hydrogen.

This behaviour can be understood if we remember that aluminium metal in air is covered with a layer of aluminium oxide. Aluminium oxide protects the metal underneath like a layer of paint. Once the acid penetrates this protective layer and comes in contact with the metal, the reaction takes place as we expected it would in the first instance.

We now have enough information about the chemical behaviour of metals to make a summary. This is done in table 21.2.

**Table 21.2:** The activity series of metals

| METALS (most active at top of list) | ACTIVITY OF METALS | | | |
|---|---|---|---|---|
| | Effect of heating the metal in air | Effect of cold water on the metal | Effect of heating the metal in steam | Effect of contact with dilute hydrochloric acid |
| potassium | forms the oxide | reacts to form hydrogen and the hydroxide | reacts to form hydrogen and the hydroxide | reacts to form hydrogen and the chloride |
| sodium | | | | |
| calcium | | | | |
| magnesium | | no action | reacts to form hydrogen and the oxide | |
| aluminium | | | | |
| iron | | | | |
| tin | | | no action | |
| lead | | | | no action |
| copper | | | | |
| mercury | no action | | | |
| silver | | | | |
| gold | | | | |

Compounds of potassium and sodium are the most difficult to decompose by heat. Compounds of gold and silver are the easiest to decompose by heat.

Notice that we have included at the bottom of the summary information not already dealt with. This information is about the effect of heat on compounds of the metals. It appears that the more violently a metal combines with another element to form a compound, the more difficult it is to decompose that compound once it is formed. This principle is illustrated by comparing the effects of heat on copper oxide and mercuric oxide.

Mercury is lower in the activity series than copper. Therefore, mercuric oxide should decompose more easily than copper oxide. This may be demonstrated by heating a little of each oxide separately in test tubes. A glowing splint is placed at the mouth of each test tube to see whether any oxygen is given off. The experiment is illustrated in figure 21.6. Mercuric oxide decomposes to mercury and oxygen while the copper oxide is unchanged. We therefore conclude that copper oxide is a more stable compound than mercuric oxide.

Experiment 21.3 compares the effect of heat on another pair of compounds — copper carbonate and sodium carbonate.

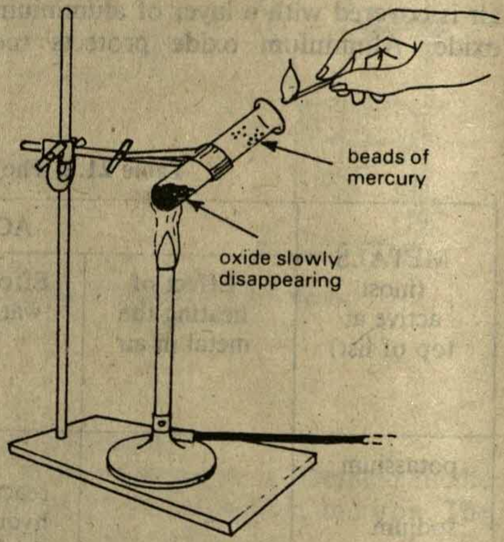


**Figure 21.6:** Heating mercuric oxide in a test tube.

**EXPERIMENT 21.1**

*Displacing copper from copper sulphate solution*

**Each group will need:**

- small strips of magnesium, zinc and lead
- fresh steel wool
- quantity of mercury with dropper (on teacher's bench)
- emery cloth
- five test tubes in stand
- about 4 g of powdered copper sulphate
- small beaker containing about 25 mL of water
- glass rod

**What to do**

- Add the copper sulphate to the water and stir to dissolve.
- Add copper sulphate solution to each of the test tubes to a depth of about 3 cm.
- Clean the strips of metal with emery cloth and drop them into separate test tubes.
- Ask your teacher to add a drop of mercury to the fifth test tube. (Don't handle mercury — it is poisonous.)
- Watch what happens. Feel each test tube to see whether there is a rise in temperature.

### Questions

21.1 Did a dull red deposit of copper form in all the test tubes? If it did not, which metal or metals failed to give a result? Tabulate your results. Place a tick opposite the metal where you obtained a positive result.

| Metal | Copper formed | Blue colour disappears | Solution becomes warm |
|---|---|---|---|
| | | | |

21.2 From the results of this experiment can you place the metals in any sort of order? Which was the least active metal? Compare your answer with the list of metals given in table 21.2.

**EXPERIMENT 21.2**

## *Testing the effect of dilute hydrochloric acid on copper, magnesium and iron*

**Each group will need:**

- pieces of clean copper, magnesium and iron
- dilute hydrochloric acid
- three test tubes in stand
- Bunsen burner
- taper or splint

**What to do**

- Add about 2 cm of dilute hydrochloric acid to each test tube.
- Light the taper in readiness to test for hydrogen.
- Drop a piece of metal into each test tube.
- Test for the presence of hydrogen by placing a lighted taper at the mouth of each test tube.

### Questions

21.3 Did all the metals react with the acid? If they did not, which of them did react? Classify the results as "very active", "active" or "inactive".

21.4 What happened with the lighted taper? A "pop" indicates the presence of hydrogen. However, if the effervescence is very slow you may not get a "pop".

**EXPERIMENT 21.3**

## *Heating sodium carbonate and copper carbonate*

**Each group will need:**

- two test tubes
- retort stand and clamp (or test tube holder)
- limewater
- Bunsen burner
- powdered sodium carbonate
- powdered copper carbonate

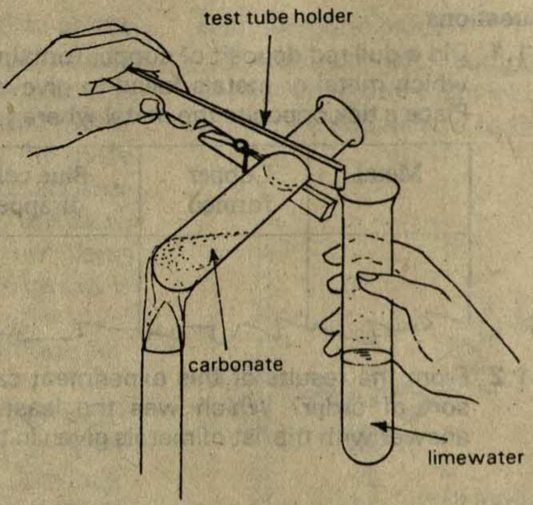


**Figure 21.7:** Heating a carbonate in a test tube.

### What to do

- Add a little sodium carbonate to one test tube and clamp it gently, as shown in figure 21.7.
- Pour about 1 cm of limewater into the second test tube and hold it in the position shown. This is to collect any carbon dioxide formed. Carbon dioxide is a heavy gas and will sink to the bottom of the test tube. Its presence will be indicated by the limewater turning cloudy.
- Heat the first test tube strongly for about five minutes. Note any change occurring in either test tube.
- Allow the first test tube to cool and empty out the residue. Don't wash out this test tube — it won't matter if a little powder remains.
- Add a little copper carbonate to the first test tube and some fresh limewater to the second.
- Heat the copper carbonate for five minutes and note any change occurring in either test tube.

### Questions

**21.5** Was there any change in the appearance of either carbonate? If so, describe it. Did the limewater change?

**21.6** Which substance seemed to be easier to decompose by heat? Does your statement tally with the statement at the bottom of table 20.2?

## The activity series of metals

1. Very active metals:

| | |
|---|---|
| potassium | K |
| sodium | Na |
| calcium | Ca |

2. Active metals:

| | |
|---|---|
| magnesium | Mg |
| aluminium | Al |
| zinc | Zn |
| iron | Fe |
| tin | Sn |

3. Less active metals:

| | |
|---|---|
| lead | Pb |
| copper | Cu |
| mercury | Hg |
| silver | Ag |
| gold | Au |

## Spelling list

activity
aluminium
asbestos
corrode
effervescence
haematite
hydrochloric acid
litmus
pyrites
violent

## Things to do

**21.7** Add a piece of clean copper to a solution of mercuric chloride. What happens?

**21.8** Heat about a third of a test-tube-full of concentrated copper sulphate solution. When the solution is almost boiling, pour it on to some steel wool in a second test tube in a rack. Notice how violent the reaction is.

**21.9** Prepare green crystals of iron sulphate by using 8 g of iron nails and 50 mL of dilute sulphuric acid (1M) in a conical flask. Warm the mixture to start it off. When the reaction has finished, filter into a second conical flask. Stopper the flask to exclude air and allow to stand overnight.

**21.10** Place a few drops of each of the following solutions on a white tile — copper sulphate, magnesium sulphate, zinc sulphate and lead nitrate. Place a small piece of zinc in each solution. Examine with a hand lens. Repeat, using a fresh lot of drops on the tile each time, using the metals iron, copper, magnesium and lead. Use your results to place the metals in the order of their chemical activity.

## More questions

**21.11** What evidence can you give that magnesium is more active than copper? Number each fact you give.

**21.12** How is sodium usually stored? Why is it stored in this way?

**21.13** When magnesium is burnt in steam, hydrogen is produced. Does the hydrogen come from the metal or the steam? Why?

**21.14** Would you expect gold to react with water? Give your reasons.

**21.15** How would you distinguish between a piece of tin and a piece of silver?

**21.16** What are some of the methods used to prevent iron from rusting? Why is rust such a problem? What steps are taken by some car manufacturers to prevent rust? (R)

**21.17** Which set of saucepans would you expect to last longer — an aluminium set or a copper set? Explain.

**21.18** Railway operators in Australia are tending to use stainless steel carriages in preference to steel ones. Why do they do this, when stainless steel is much more expensive than ordinary steel?

## Test yourself (chapter 21)

Write the answers to questions 1 to 3 in your workbook.

1. Name a metal more active than iron but less active than calcium.
2. Name a metal more active than mercury but less active than iron.
3. Name a metal that will not burn when heated in air.

Choose the best answer to each of questions 4 to 8 and write its letter in your workbook.

4. Of the following, the metal that will release hydrogen from cold water is
   (a) iron
   (b) calcium
   (c) copper
   (d) zinc?
5. Silver can be readily distinguished from zinc by the immediate effect on each of
   (a) water
   (b) limewater
   (c) dilute hydrochloric acid
   (d) a solution of magnesium sulphate.
6. Pieces of copper are dropped into each of the following solutions. A chemical action takes place in only one solution. Which solution is it?
   (a) silver nitrate
   (b) zinc sulphate
   (c) copper chloride
   (d) iron sulphate.

7. In which of the following groupings are the metals in the order of their chemical activity with the most active metal first?
   (a) aluminium, copper, iron, lead
   (b) copper, aluminium, lead, iron
   (c) aluminium, iron, lead, copper
   (d) iron, aluminium, copper, lead.
8. The metal copper was discovered and used centuries before iron was. The most likely explanation for this is:
   (a) Copper compounds decompose more readily than iron compounds.
   (b) Copper is more plentiful than iron.
   (c) Copper is softer than iron and therefore easier to shape.
   (d) Many copper ores are brightly coloured and therefore easier to see than the duller iron ores.

# 22

# Extraction of metals

Some metals are found free (uncombined, or "native") in nature. These include tin, copper, mercury, silver and gold. However, most metals present in the earth's crust occur in compounds. Examples of these compounds are silicates, oxides, sulphides and carbonates.

Compounds from which metals are extracted for use are called ores. Most ores are either sulphides or oxides. Table 22.1 lists some well-known ores.

**Table 22.1:** Some ores of metals

| Ore | Formula | Metal extracted |
|---|---|---|
| haematite | $Fe_2O_3$ | iron |
| iron pyrites | $FeS_2$ | iron |
| copper pyrites (chalcopyrite) | $CuS.FeS$ | copper |
| bauxite | $Al_2O_3.3H_2O$ | aluminium |
| pentlandite | $NiS.2FeS$ | nickel |
| galena | $PbS$ | lead |

## Reduction of ores to the metal

Ores of less active metals are easier to reduce than ores of active metals. For example, it is easier to convert haematite to iron than bauxite to aluminium. The aluminium in bauxite is combined more strongly with oxygen than is the iron in haematite.

The nature of the ore is also important. For example, iron ore is a simple oxide whereas copper pyrites (chalcopyrite) is a compound containing both iron and copper. This makes it more difficult to recover copper from its ore even though copper compounds are more easily decomposed than iron compounds.

## Reduction of oxide with carbon

A simple experiment that illustrates this kind of reduction is the heating of copper oxide with charcoal. This is done by first gouging a hole about half a centimetre deep in a block of charcoal. Into this hole is placed some copper oxide. The oxide is heated by directing a burner flame on to it with a blowpipe. To do this the burner flame should be turned low and the air supply shut off.

After heating the copper oxide for a few minutes you will notice a thin film of copper in the hole. (See figure 22.1.)

$$\begin{array}{ccccccc} \text{copper oxide} & + & \text{carbon} & \rightarrow & \text{copper} & + & \text{carbon monoxide} \\ CuO & + & C & \rightarrow & Cu & + & CO\uparrow \end{array}$$

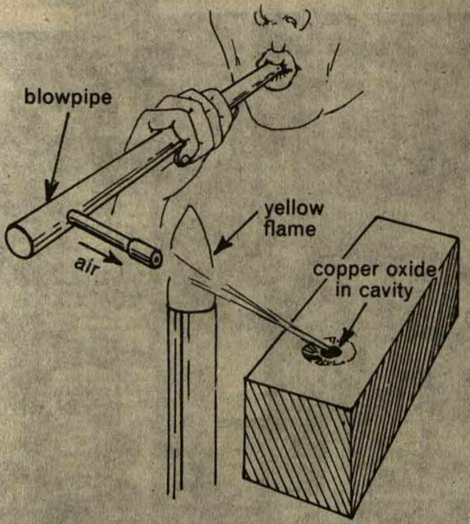


**Figure 22.1:** The reduction of copper oxide on a charcoal block. The copper appears as a fine powder in the hole after the copper oxide is heated for several minutes.

Carbon monoxide tends to be formed rather than carbon dioxide because there is a lot of carbon and only a small amount of oxygen. If there were a little carbon and a lot of oxygen, carbon dioxide would be formed.

An important reaction in steel works is the reduction of haematite to iron in the blast furnace. (See figures 22.2 and 22.3.) Coke is used instead of charcoal to supply the carbon. A fire is first lit in the furnace and the charge, consisting of haematite, coke and limestone, is fed in at the top. Hot air or oxygen is blasted in at the bottom. The burning of the coke in this oxygen supplies the heat for the reduction of the ore. The following equation gives a simplified explanation of this reduction.

$$\begin{array}{ccccccc} \text{haematite} & + & \text{carbon} & \rightarrow & \text{iron} & + & \text{carbon monoxide} \\ Fe_2O_3 & + & 3C & \rightarrow & 2Fe & + & 3CO\uparrow \end{array}$$

The limestone is added to combine with the sandy material that is generally present with the ore.

$$\begin{array}{ccccccc} \text{limestone} & + & \text{sand} & \rightarrow & \text{calcium silicate} & + & \text{carbon dioxide} \\ CaCO_3 & + & SiO_2 & \rightarrow & CaSiO_3 & + & CO_2\uparrow \end{array}$$

The calcium silicate accumulates as a black glassy liquid on top of the molten iron. It is called slag. The iron and the slag can be drained off separately.

## Roasting the ore in air

Many ores, such as the ores of nickel, lead and zinc, are sulphides. Such ores cannot be successfully reduced by heating them with charcoal in a blast furnace. They first have to be changed to

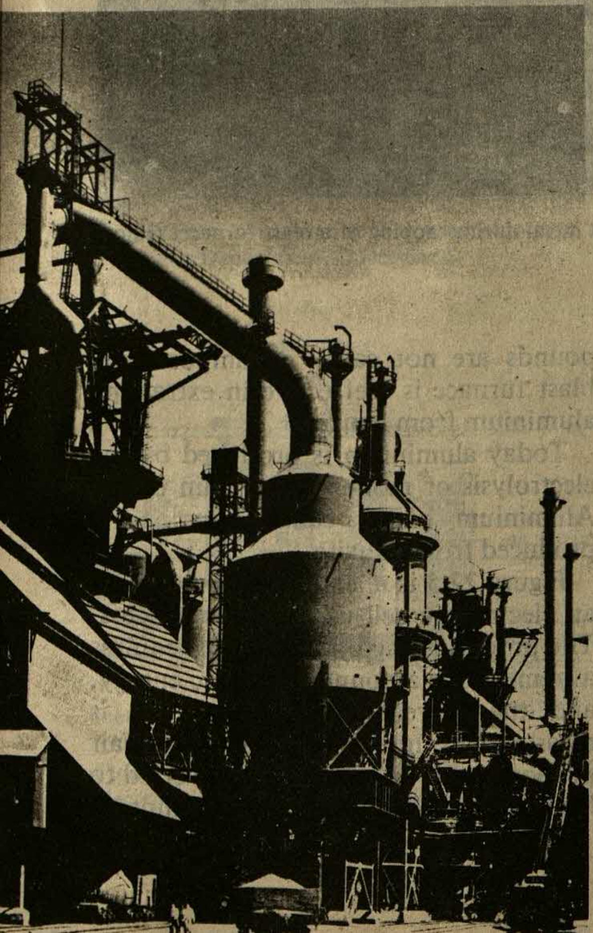


**Figure 22.2:** View of a blast furnace at Port Kembla steelworks. The tall structure on the left is the actual furnace. The charge is fed in at the top by skip trucks. The molten iron is drawn off at the bottom into a hot-metal transfer car. This car is shown left of centre in the foreground. (Photo courtesy B.H.P. Co. Ltd)

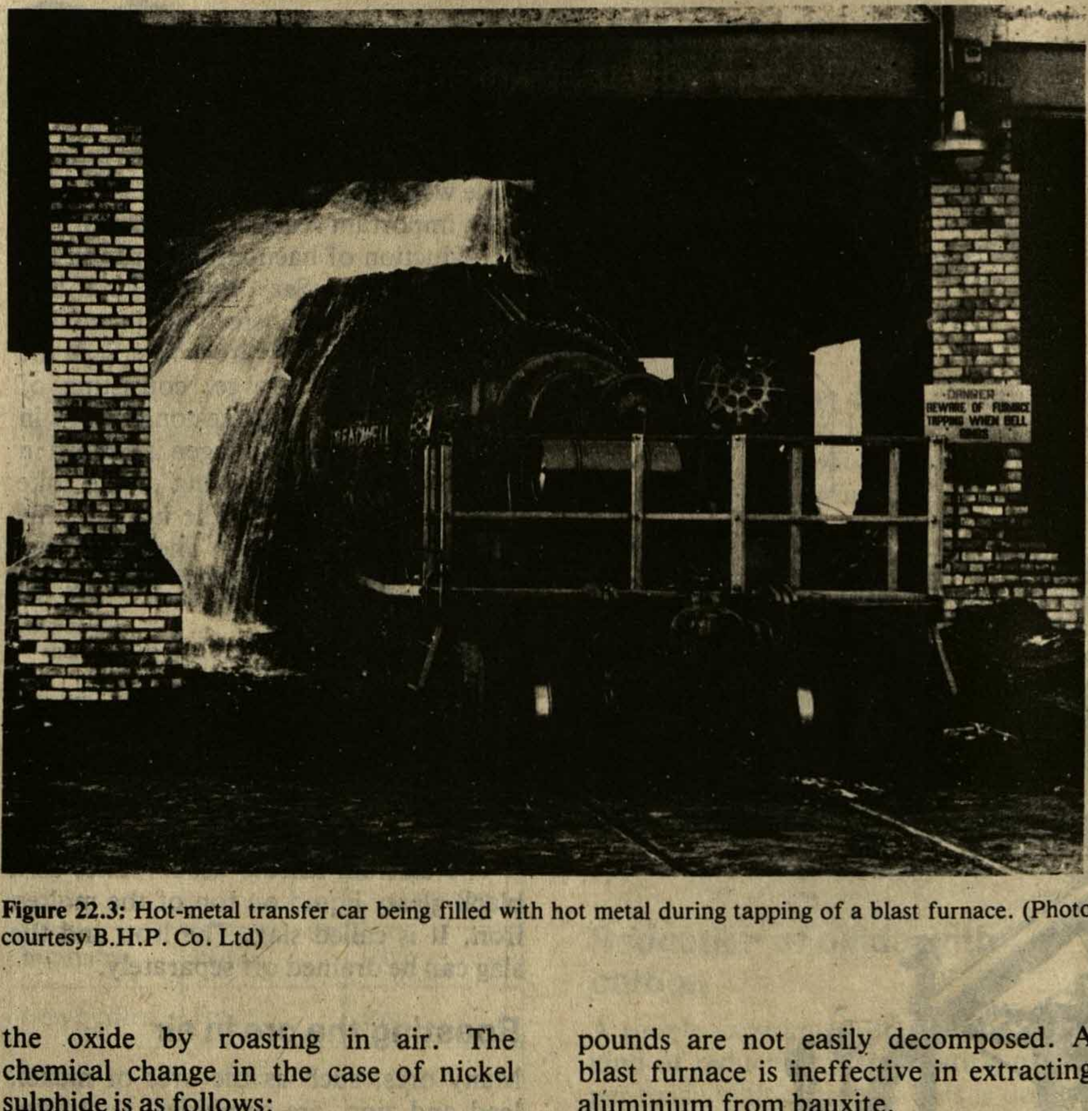


**Figure 22.3:** Hot-metal transfer car being filled with hot metal during tapping of a blast furnace. (Photo courtesy B.H.P. Co. Ltd)

the oxide by roasting in air. The chemical change in the case of nickel sulphide is as follows:

$$\text{nickel sulphide} + \text{oxygen (from air)} \rightarrow \text{nickel oxide} + \text{sulphur dioxide}$$

$$NiS + O_2 \rightarrow NiO + SO_2 \quad \text{(unbalanced)}$$

$$2NiS + 3O_2 \rightarrow 2NiO + 2SO_2 \quad \text{(balanced)}$$

## Reduction by electrolysis

As mentioned earlier, it requires a lot of energy to extract aluminium from bauxite. This is because aluminium is high in the activity series and therefore its compounds are not easily decomposed. A blast furnace is ineffective in extracting aluminium from bauxite.

Today aluminium is produced by the electrolysis of molten aluminium oxide. Aluminium oxide, called alumina, is produced from bauxite.

Figure 22.5 is a simplified diagram of an electrolytic cell used in this process. The process going on in the cell requires a tremendous amount of electric energy, and the current through the cell is measured in thousands of amps. A fair proportion of this energy is converted to heat and this maintains the alumina in

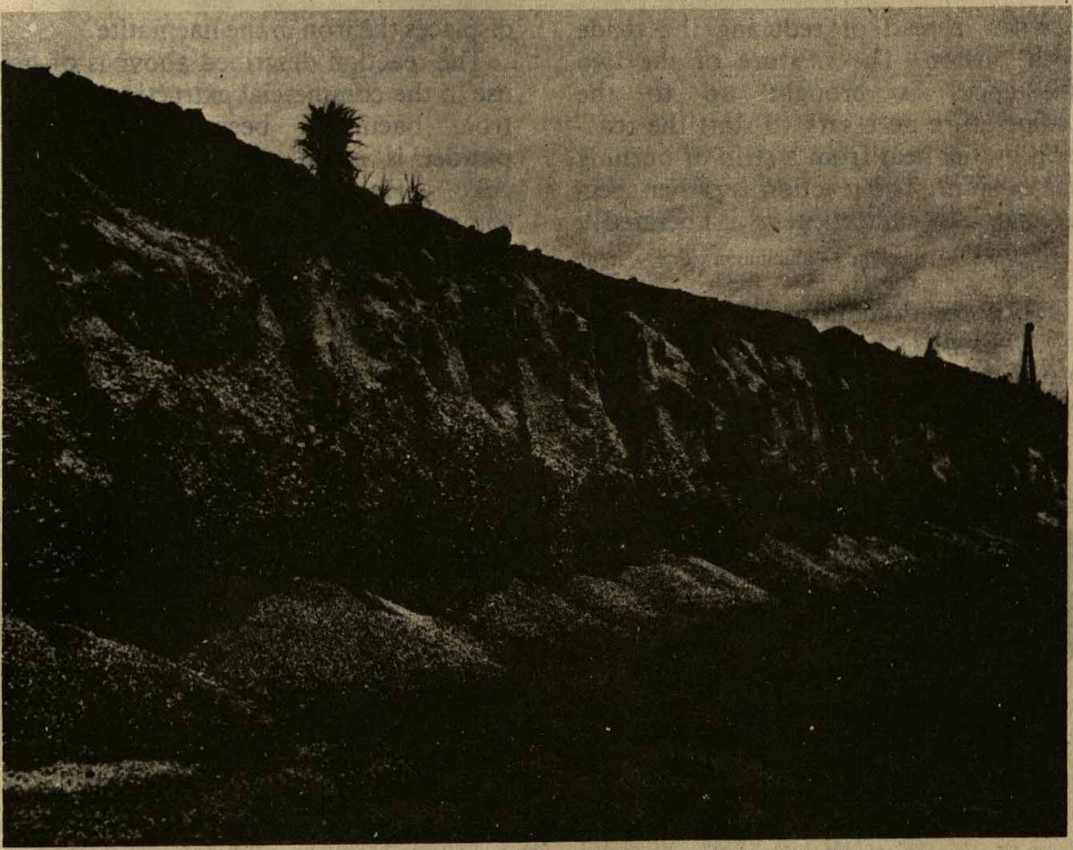


**Figure 22.4:** These bauxite cliffs at Weipa, north Queensland, give some indication of how extensive the deposits are. Ore mined at Weipa is transported by bulk carrier to Gladstone for refining. (Photo courtesy Premier's Department, Queensland)

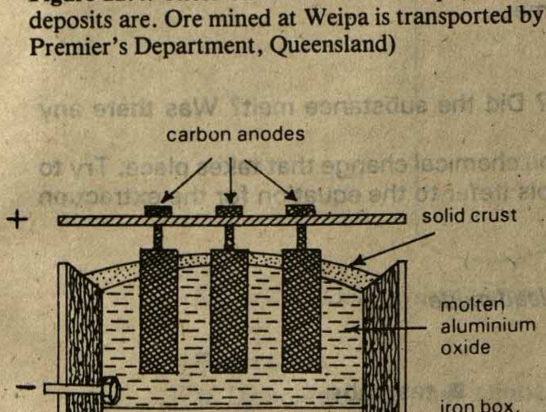

carbon anodes
+
solid crust
molten aluminium oxide
−
iron box, lined with graphite, that acts as cathode
molten aluminium collects on cathode

**Figure 22.5:** The production of aluminium by the electrolysis of molten aluminium oxide.

the molten state. The aluminium ions are attracted to the negative electrode and the oxide ions to the positive electrode.

Aluminium is a very useful metal. It does not corrode like iron. It is light, ductile and malleable. Today it is used in the manufacture of a variety of products, ranging from wrapping foil to aircraft bodies.

## Heating the oxide with another metal

It is possible to extract iron from haematite by heating it with aluminium powder instead of reducing the oxide with carbon. The mixture of the two substances is brought up to the temperature necessary to start the reaction by the heat from a strip of burning magnesium. The reaction is rather spectacular; a lot of heat energy is liberated.

aluminium + haematite → aluminium oxide + iron

$$2Al + Fe_2O_3 \rightarrow Al_2O_3 + 2Fe$$

This reaction takes place because aluminium is a more active metal than iron. Therefore it combines with oxygen with greater strength and for this reason displaces the iron in the haematite.

The reaction described above is of no use in the commercial extraction of iron from haematite because aluminium powder is much more expensive than coke. However, the reaction is sometimes used to weld steel rails together on the track. This is called the thermite process. The mixture of iron oxide and aluminium powder is packed in the gap between the rails. It is fired by a fuse and the molten iron that is liberated fills the gap and joins the rails.

**EXPERIMENT** *Roasting galena in air*

**22.1**

**Each group will need:**

- crucible lid
- pipeclay triangle
- tripod
- small piece of galena
- Bunsen burner
- mortar and pestle

**What to do**

- Powder the galena in a mortar.
- Place the powder in a crucible lid on a tripod.
- Heat strongly with a Bunsen flame.

**Questions**

**22.1** Did any change take place? Did the substance melt? Was there any change in colour?

**22.2** Write a word equation for the chemical change that takes place. Try to write the equation in symbols (refer to the equation for the extraction of nickel in the text).

**EXPERIMENT** *Heating a mixture of charcoal and lead oxide*

**22.2**

**Each group will need:**

- enough powdered charcoal to cover a 2 cent piece
- twice as much litharge (lead oxide)
- test tube
- retort stand and clamp
- Bunsen burner
- mortar and pestle

**What to do**

- Grind the mixture together in the mortar.
- Transfer it to the test tube using a piece of paper folded as a V.

- Clamp the test tube horizontally in the stand.
- Heat the mixture with a Bunsen flame. Avoid breathing any fumes, as lead is poisonous.

**Questions**

22.3 What change occurred? Was any lead formed?
22.4 Write a word equation for the reaction. Try to write the equation in symbols.

**EXPERIMENT 22.3**

### *Extracting copper by electrolysis*

**Each group will need:**

- small quantity of powdered copper sulphate (enough to cover a 2 cent piece)
- 100 mL beaker
- one electric cell, or power pack
- connecting wire
- two small graphite electrodes (centre rods from torch cells will be adequate)
- two alligator clips
- switch
- electric bulb and socket

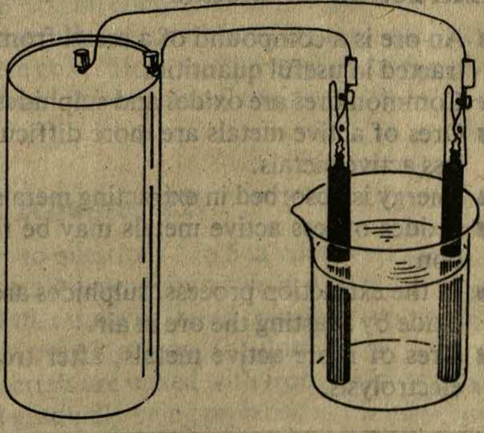


**Figure 22.6:** Electrolysis of copper sulphate using carbon electrodes.

**What to do**

- Dissolve the copper sulphate in about 50 mL of water.
- Set up the apparatus as shown in figure 22.6.
- Switch on the current for about five minutes.

**Questions**

22.5 Did you notice a deposit of copper forming? Where was it deposited?
22.6 Did the formation of copper from copper sulphate require an input of energy; or was energy given out during the change?

EXPERIMENT

22.4

### *Heating a mixture of iron powder and copper oxide*

**Each group will need:**

- iron powder (not iron filings)
- copper oxide (may be prepared by heating a precipitate of copper hydroxide)
- crucible lid
- pipeclay triangle
- tripod
- Bunsen burner
- glass rod

**What to do**

- Prepare half a teaspoonful of mixture, using about equal proportions by volume of the copper oxide and the powdered iron.
- Heat the mixture of iron and copper oxide on the crucible lid. Look for any traces of copper beneath the surface by stirring with the glass rod.

**Questions**

**22.7** Did you see any copper in the mixture after heating? What is likely to happen to any copper formed on the surface of the mixture?

## Extraction of metals

- An ore is a compound of a metal from which the metal may be extracted in useful quantities.
- Common ores are oxides and sulphides of metals.
- Ores of active metals are more difficult to reduce than are ores of less active metals.
- Energy is absorbed in extracting metals from ores.
- Oxides of less active metals may be reduced by heating with carbon.
- In the extraction process, sulphides are usually first changed to the oxide by roasting the ore in air.
- Ores of more active metals, after treatment, are decomposed by electrolysis.

## Spelling list

accumulate
bauxite
chalcopyrite
crucible
electrolysis
galena
gouge
haematite
litharge
pentlandite
pyrites
thermite

## Things to do

22.8 Draw a map of Australia and on it mark the main places where ores are mined.

22.9 Metals are used to make many different things — without metals we would be back in stone-age conditions. But mining scars the landscape and sometimes completely destroys natural areas. Choose a particular example of conflict between mining and conservation interests and find out how problems were solved, or what problems remain unsolved.

## More questions

22.10 Why have blast furnaces been built at the New South Wales towns of Port Kembla and Newcastle, a long way from deposits of iron ore?

22.11 Pure gold and silver are rarely used in making jewellery. Why? What is usually done to them? (R)

22.12 What is the ore of tin? How is it mined? How is the metal extracted? (R)

22.13 Australia has huge deposits of bauxite. Why then is aluminium such an expensive metal compared with iron?

22.14 In the nineteenth century blast furnaces used charcoal. Later they began to use coke. How are charcoal and coke made? Why did steel makers change from charcoal to coke? (R)

## Test yourself (chapter 22)

Write the answers to questions 1 to 5 in your workbook.

1. Name three metals never found free in nature.
2. Name a metal that is never found combined in nature.
3. Name the main ore of (a) iron, (b) aluminium.
4. What two materials are mixed with iron ore in the blast furnace?
5. Name a metal gradually being replaced in the packaging of foods.

Choose the best answer to each of questions 6 to 11 and write its letter in your workbook.

6. Which of the following oxides could be most easily decomposed by heating?
   (a) mercuric oxide
   (b) magnesium oxide
   (c) lead oxide
   (d) tin oxide.
7. From which of the above oxides would it be most difficult to extract the metal?

8. Which one of the following metals would need to be extracted electrolytically from its ore?
   (a) silver
   (b) lead
   (c) magnesium
   (d) nickel.
9. Lead is usually extracted from the mineral
   (a) pyrites
   (b) haematite
   (c) galena
   (d) bauxite.
10. In which of the following reactions is energy taken in?
   (a) Hot steel wool is placed in a jar of chlorine and sparkles.
   (b) Magnesium ribbon burns with a bright white flame.
   (c) An electric current is passed through copper sulphate solution, producing copper on one of the electrodes.
   (d) An acid is added to an alkali, producing heat and a salt.
11. Iron, aluminium, copper and lead are alike in that they are all
   (a) found in nature ready for use
   (b) separated from substances found in nature
   (c) metals that do not conduct heat
   (d) easily corroded by water.

# 23

# Chemical bonding: how atoms are joined together

You may have wondered why one element is more active than another. For example, why is sodium more active than copper, and why is chlorine more active than nitrogen? And why do metals combine with non-metals but not with other metals?

These and similar questions can only be answered if we know how atoms join together or, as scientists say, are chemically bonded.

In chapter 8 we explained that atoms are made up of extremely small particles called electrons, protons and neutrons. The simplest of all atoms is the atom of hydrogen. It has only one proton and one electron. It is the only atom without a neutron. Figure 23.1 shows various ways of representing the hydrogen atom by diagrams.

If the hydrogen atom could be enlarged until it was about one kilometre across, the nucleus would have a diameter of only one centimetre. This is not very much different in scale from the moon orbiting the earth. You can therefore understand why we say an atom is mostly empty space.

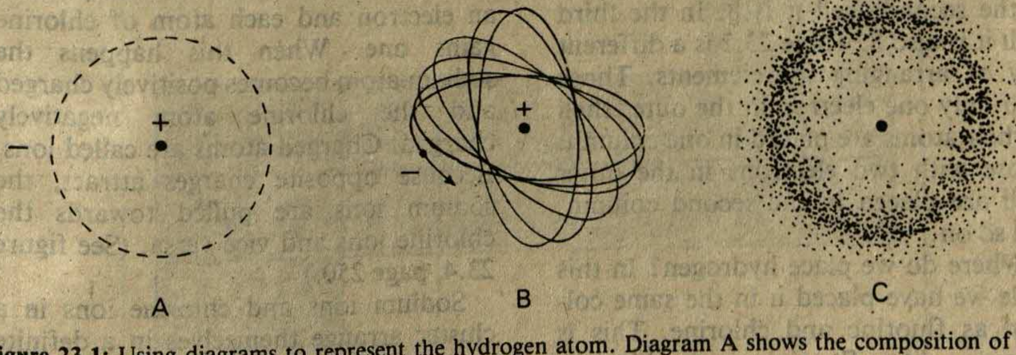


**Figure 23.1:** Using diagrams to represent the hydrogen atom. Diagram A shows the composition of the atom — one proton and one electron. Diagram B shows how the electron revolves about the proton in overlapping orbits. This revolution is extremely rapid and produces the cloud effect shown in diagram C in the same way as a rapidly spinning aircraft propeller creates the illusion of a disc.

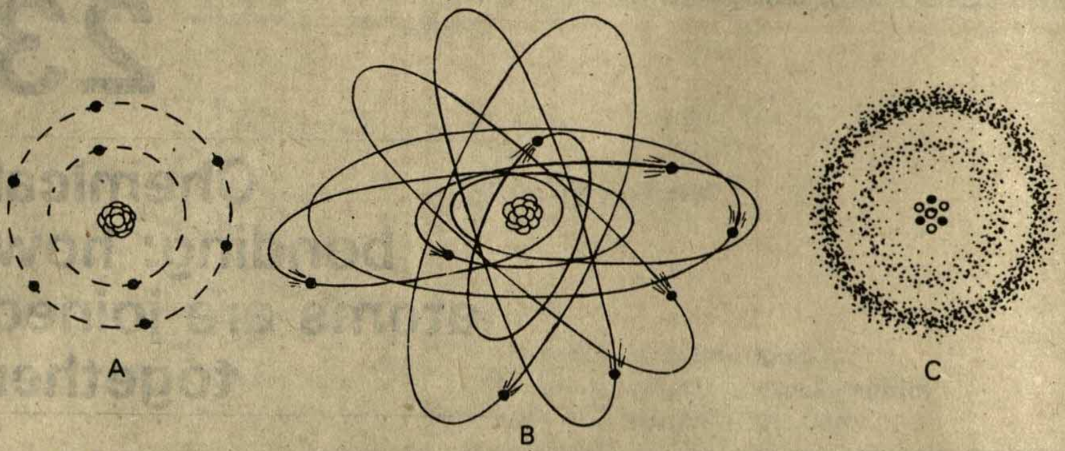


**Figure 23.2:** Diagrams representing the oxygen atom. Notice that the electrons are in two zones or shells. The first shell contains two electrons, the second shell six. Two is the greatest number of electrons that can be held in the first shell.

The three diagrams in figure 23.2 all represent the oxygen atom. This atom has eight electrons orbiting the nucleus. Notice that two are close to the nucleus and the remainder are further out. This is a property of atoms: the electrons appear to move in different zones, or shells.

Table 23.1 is a list of the first twenty elements. It shows what each atom has in its nucleus and how the electrons are distributed around it.

Table 23.1 shows that the maximum number of electrons in the first shell is 2. In the second shell it is 8. In the third shell it is also 8. Table 23.2 is a different way of arranging the elements. Those with only one electron in the outer shell of their atoms are placed in one column. Those with two electrons in the outer shell are placed in the second column, and so on.

Where do we place hydrogen? In this table we have placed it in the same column as fluorine and chlorine. This is because, like fluorine and chlorine, hydrogen needs only one electron to complete a stable outer shell.

## The ionic bond

When warm sodium is placed in a jar of chlorine gas a vigorous chemical reaction follows. The sodium combines with chlorine to form a white deposit of sodium chloride (common salt). A lot of heat is given out. We therefore assume that the compound, sodium chloride, is a more stable arrangement of the atoms than is the metal-gas mixture.

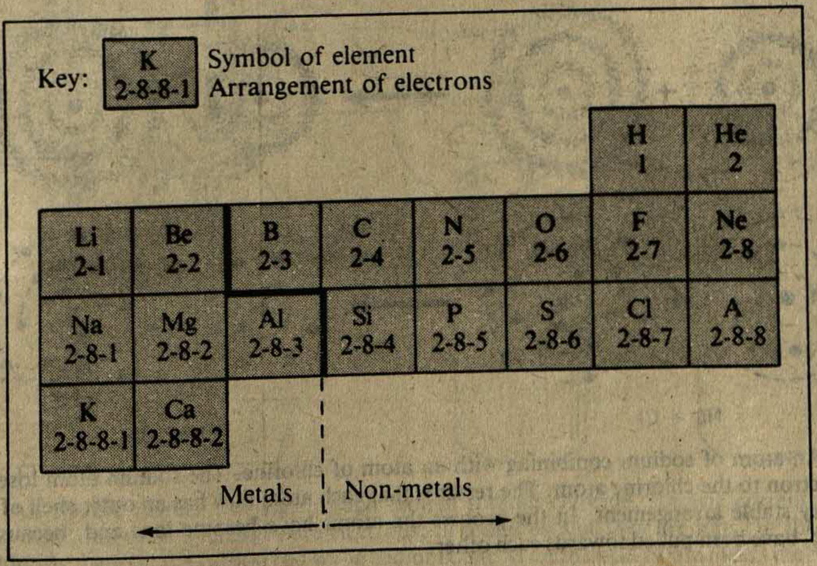
What happens to the atoms in this chemical reaction? The evidence indicates that each atom of sodium loses an electron and each atom of chlorine gains one. When this happens the sodium atom becomes positively charged and the chlorine atom negatively charged. Charged atoms are called ions. Because opposite charges attract, the sodium ions are pulled towards the chlorine ions and vice versa. (See figure 23.4, page 250.)

Sodium ions and chlorine ions in a cluster arrange themselves in a definite geometric pattern. Each sodium ion surrounds itself with six chlorine ions and each chlorine ion surrounds itself with

**Table 23.1:** Details of the atoms of the first twenty elements

| Element | Symbol | Nucleus | | Electrons in shells | | | |
|---|---|---|---|---|---|---|---|
| | | Protons | Neutrons | First | Second | Third | Fourth |
| hydrogen | H | 1 | — | 1 | — | — | — |
| helium | He | 2 | 2 | 2 | — | — | — |
| lithium | Li | 3 | 4 | 2 | 1 | — | — |
| beryllium | Be | 4 | 5 | 2 | 2 | — | — |
| boron | B | 5 | 6 | 2 | 3 | — | — |
| carbon | C | 6 | 6 | 2 | 4 | — | — |
| nitrogen | N | 7 | 7 | 2 | 5 | — | — |
| oxygen | O | 8 | 8 | 2 | 6 | — | — |
| fluorine | F | 9 | 10 | 2 | 7 | — | — |
| neon | Ne | 10 | 10 | 2 | 8 | — | — |
| sodium | Na | 11 | 12 | 2 | 8 | 1 | — |
| magnesium | Mg | 12 | 12 | 2 | 8 | 2 | — |
| aluminium | Al | 13 | 14 | 2 | 8 | 3 | — |
| silicon | Si | 14 | 14 | 2 | 8 | 4 | — |
| phosphorus | P | 15 | 16 | 2 | 8 | 5 | — |
| sulphur | S | 16 | 16 | 2 | 8 | 6 | — |
| chlorine | Cl | 17 | 18 | 2 | 8 | 7 | — |
| argon | A | 18 | 22 | 2 | 8 | 8 | — |
| potassium | K | 19 | 20 | 2 | 8 | 8 | 1 |
| calcium | Ca | 20 | 20 | 2 | 8 | 8 | 2 |

**Table 23.2:** The first twenty elements



Key: K 2-8-8-1 Symbol of element
Arrangement of electrons

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | H<br>1 | He<br>2 |
| Li<br>2-1 | Be<br>2-2 | B<br>2-3 | C<br>2-4 | N<br>2-5 | O<br>2-6 | F<br>2-7 | Ne<br>2-8 |
| Na<br>2-8-1 | Mg<br>2-8-2 | Al<br>2-8-3 | Si<br>2-8-4 | P<br>2-8-5 | S<br>2-8-6 | Cl<br>2-8-7 | A<br>2-8-8 |
| K<br>2-8-8-1 | Ca<br>2-8-8-2 | | | | | | |

Metals | Non-metals

six sodium ions. Such an arrangement produces a cubic structure (remember that a cube has six equal sides). Figure 23.5A is a drawing of a cluster of sodium and chlorine ions to show the cubic shape of the resultant mass. Figure 23.5B is a photo of some crystals of sodium chloride, also showing the cubic shape.

One experiment that gives evidence for the presence of ions in sodium chloride is illustrated in figure 23.6. Solid sodium chloride will not conduct electricity but the molten salt will. In molten sodium chloride the ions are free to move (mobile). The positive ions move towards the negative electrode and the negative ions towards the positive electrode.

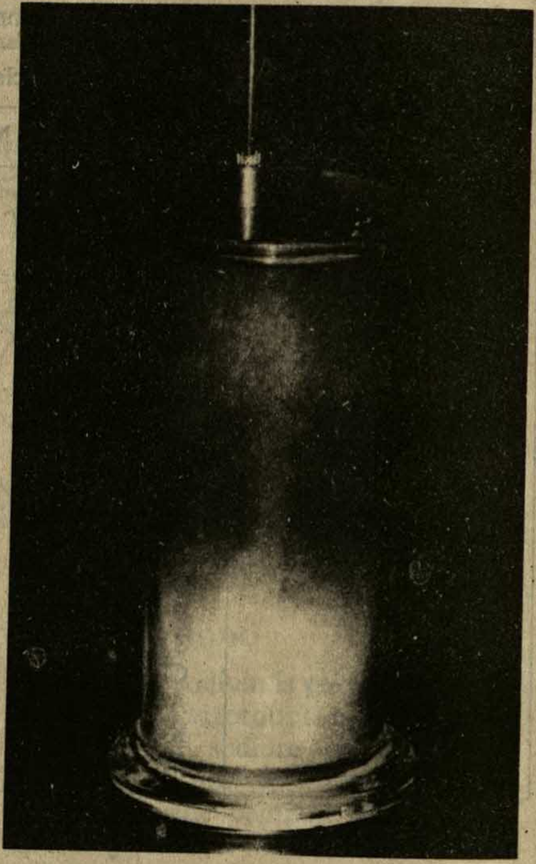


**Figure 23.3:** Sodium combines readily with chlorine to form a white deposit of sodium chloride (common salt). A lot of heat is given out during the reaction, indicating that the compound sodium chloride is more stable than a mixture of the two elements. This experiment should be done with care. Use a very small piece of sodium, no bigger than a pea.

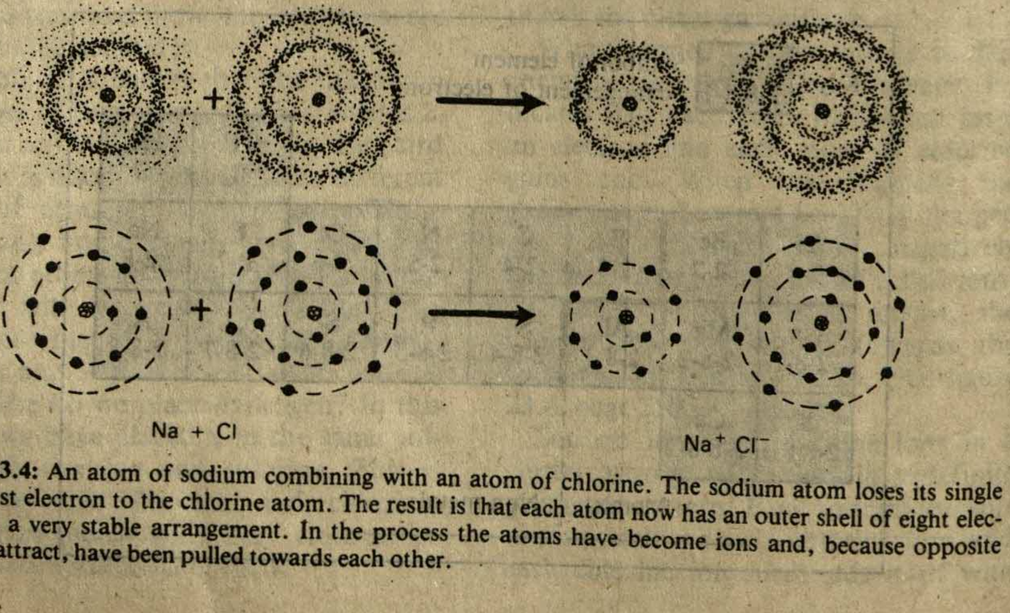


**Figure 23.4:** An atom of sodium combining with an atom of chlorine. The sodium atom loses its single outermost electron to the chlorine atom. The result is that each atom now has an outer shell of eight electrons — a very stable arrangement. In the process the atoms have become ions and, because opposite charges attract, have been pulled towards each other.

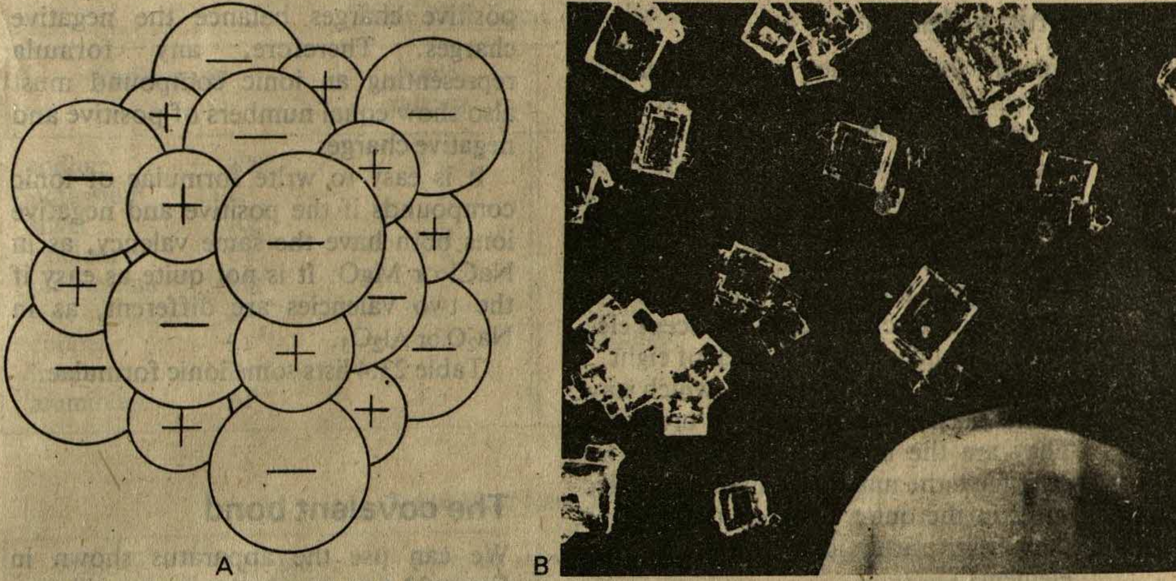


**Figure 23.5:** Crystals of sodium chloride have a cubic shape. A cube has six equal sides. The diagram (A) shows how, in a crystal of sodium chloride, each sodium ion is surrounded by six identical chlorine ions. Likewise, each chlorine ion is surrounded by six sodium ions. The photograph (B) shows some crystals of sodium chloride.

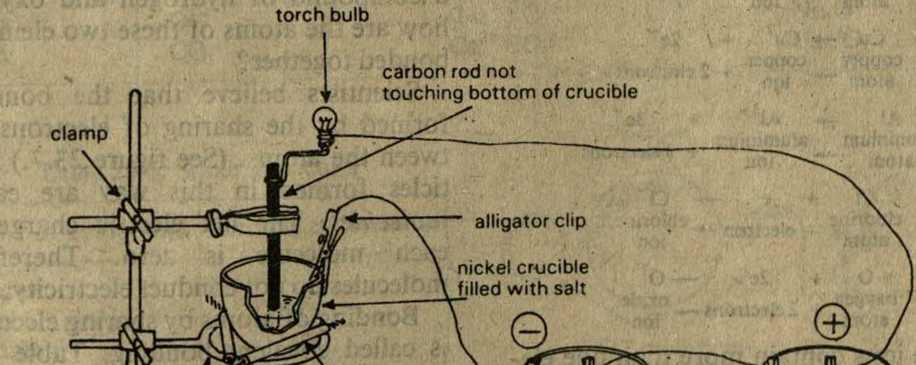


**Figure 23.6:** An electric current flowing through molten sodium chloride. Electric currents are moving charges. In a metal the moving charges are electrons; in a molten salt they are ions. In this experiment bubbles of chlorine form on the carbon rod while sodium collects on the wall of the nickel crucible.

## Ionic valency

Ions are formed when atoms either lose or gain electrons. In table 23.2 you can see that the atoms of metals have only one, two or three electrons in the outer shell. These atoms tend to lose electrons. The atoms of the non-metals have four, five, six, seven or eight electrons in the outer shell. Those with the five, six or seven outer electrons tend to accept electrons to build a complete shell of eight.

Helium, neon and argon, which have stable electron arrangements, are gases. They are the inert gases. Because they each have the maximum number of electrons in the outer shells of their atoms, they very rarely combine with other elements.

Some examples of the formation of ions are given below.

$$\mathrm{Na} \rightarrow \mathrm{Na}^{+} + e^{-}$$
sodium atom → sodium ion + electron

$$\mathrm{Cu} \rightarrow \mathrm{Cu}^{2+} + 2e^{-}$$
copper atom → copper ion + 2 electrons

$$\mathrm{Al} \rightarrow \mathrm{Al}^{3+} + 3e^{-}$$
aluminium atom → aluminium ion + 3 electrons

$$\mathrm{Cl} + e^{-} \rightarrow \mathrm{Cl}^{-}$$
chlorine atom + electron → chlorine ion

$$\mathrm{O} + 2e^{-} \rightarrow \mathrm{O}^{2-}$$
oxygen atom + 2 electrons → oxide ion

Some ions contain more than one element. Examples of these are:

| | |
|---|---|
| sulphate ion | $SO_4{}^{2-}$ |
| nitrate ion | $NO_3{}^{-}$ |
| hydroxide ion | $OH^{-}$ |

Table 23.3 lists some common ionic valencies. Notice that the ionic valency is the charge on the ion; it may be positive or negative.

Any sample of an ionic compound is electrically neutral. Even though the sample contains millions of ions, the positive charges balance the negative charges. Therefore, any formula representing an ionic compound must also show equal numbers of positive and negative charges.

It is easy to write formulae of ionic compounds if the positive and negative ions both have the same valency, as in NaCl or MgO. It is not quite as easy if the two valencies are different, as in $Na_2O$ or $Al_2O_3$.

Table 23.4 lists some ionic formulae.

## The covalent bond

We can use the apparatus shown in figure 23.6 to see whether water will conduct electricity. The test shows that water is a non-conductor. Water obviously has no ions. Seeing that water is a compound of hydrogen and oxygen, how are the atoms of these two elements bonded together?

Scientists believe that the bond is formed by the sharing of electrons between the atoms. (See figure 23.7.) Particles formed in this way are called *molecules*. The net electric charge on each molecule is zero. Therefore, molecules do not conduct electricity.

Bonding of atoms by sharing electrons is called covalent bonding. Table 23.5 lists some covalent compounds. Notice that they are all compounds of non-metals.

**Table 23.3:** Some ionic valencies

| Positive ion | | Ionic valency | Negative ion | | Ionic valency |
|---|---|---|---|---|---|
| sodium | $Na^+$ | +1 | chloride | $Cl^-$ | −1 |
| potassium | $K^+$ | +1 | hydroxide | $OH^-$ | −1 |
| silver | $Ag^+$ | +1 | nitrate | $NO_3^-$ | −1 |
| calcium | $Ca^{2+}$ | +2 | oxide | $O^{2-}$ | −2 |
| magnesium | $Mg^{2+}$ | +2 | carbonate | $CO_3^{2-}$ | −2 |
| zinc | $Zn^{2+}$ | +2 | sulphate | $SO_4^{2-}$ | −2 |
| copper | $Cu^{2+}$ | +2 | phosphate | $PO_4^{3-}$ | −3 |
| iron | $Fe^{2+}$ | +2 | | | |
| aluminium | $Al^{3+}$ | +3 | | | |

**Table 23.4:** Ionic formulae

| Positive ion | Negative ion | Formula showing charges balanced in compound | Usual formula of compound |
|---|---|---|---|
| $Na^+$ | $Cl^-$ | $Na^+Cl^-$ | $NaCl$ |
| $Cu^{2+}$ | $Cl^-$ | $Cu^{2+}(Cl^-)_2$ | $CuCl_2$ |
| $Al^{3+}$ | $O^{2-}$ | $(Al^{3+})_2(O^{2-})_3$ | |
| $Na^+$ | $O^{2-}$ | $(Na^+)_2O^{2-}$ | $Na_2O$ |
| $Ca^{2+}$ | $CO_3^{2-}$ | $Ca^{2+}CO_3^{2-}$ | $CaCO_3$ |

**Table 23.5:** Some molecules

| Name of compound | Formula of molecule |
|---|---|
| water | $H_2O$ |
| carbon dioxide | $CO_2$ |
| ammonia | $NH_3$ |
| methane | $CH_4$ |
| methanol | $CH_3OH$ |

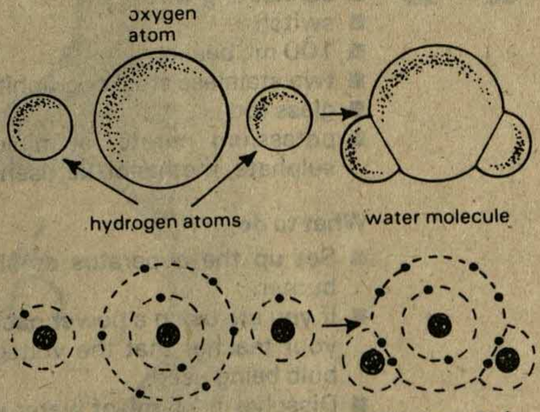


**Figure 23.7:** Water does not contain ions. It is made up of particles in which electrons are shared between the atoms. These particles are called molecules. The net charge on each molecule is zero. Note that each atom in the molecule has complete electron shells — each hydrogen atom has two electrons and the oxygen atom has an outer shell of eight.

## Molecules of those elements that are gases

Elements that are gases include hydrogen, oxygen, nitrogen and chlorine. These gases exist as molecules. The molecules are formed by atoms joining together with covalent bonds, as in figure 23.8, which shows the molecules of oxygen and nitrogen.

Other such molecules include hydrogen, $H_2$, and chlorine, $Cl_2$. The particles of the inert gases are single atoms. There is no tendency for the atoms to combine because they already have the maximum number of electrons in their outer shells.

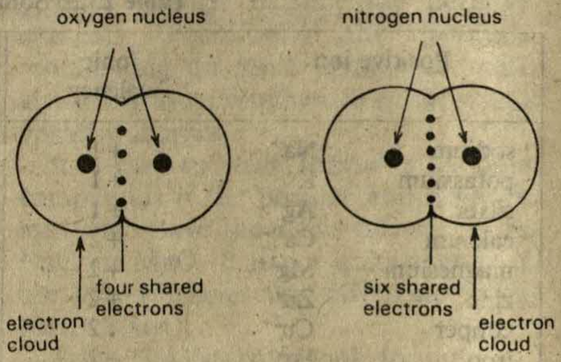


**Figure 23.8:** The molecules of oxygen and nitrogen. Each atom in these molecules is surrounded by eight electrons. This is achieved in the molecule of oxygen by sharing four electrons. In the nitrogen molecule six electrons are shared.

**EXPERIMENT**

**23.1**

### *Testing the electrical conductivity of substances*

**Each group will need:**

- six volt battery, or power pack
- six volt bulb with socket
- connecting wire
- switch
- 100 mL beaker
- two stainless steel or graphite electrodes
- glass rod
- potassium nitrate, aluminium sulphate, copper sulphate, magnesium sulphate, methanol, kerosene, carbon tetrachloride

**What to do**

- Set up the apparatus as shown in figure 23.6, excluding the Bunsen burner.
- If you are using a power pack make sure it is switched to D.C. Check with your teacher that the voltage setting corresponds to the voltage of the bulb being used.
- Dissolve in 25 mL of water about as much potassium nitrate as will cover a 10 cent piece.
- Insert the electrodes, close the switch and check to see whether the bulb lights.
- Repeat with each of the other powders.
- Clean the beaker thoroughly, add about 25 mL of methanol and test for conductivity.
- Repeat the procedure with each of the other liquids.

- Tabulate your results as follows, using a tick for a positive result.

| Substance tested | Did bulb light? | Indicates presence of: | |
|---|---|---|---|
| | | ions | molecules |
| | | | |

**EXPERIMENT**

**23.2**

### *Making up the chemical formulae of ionic compounds*

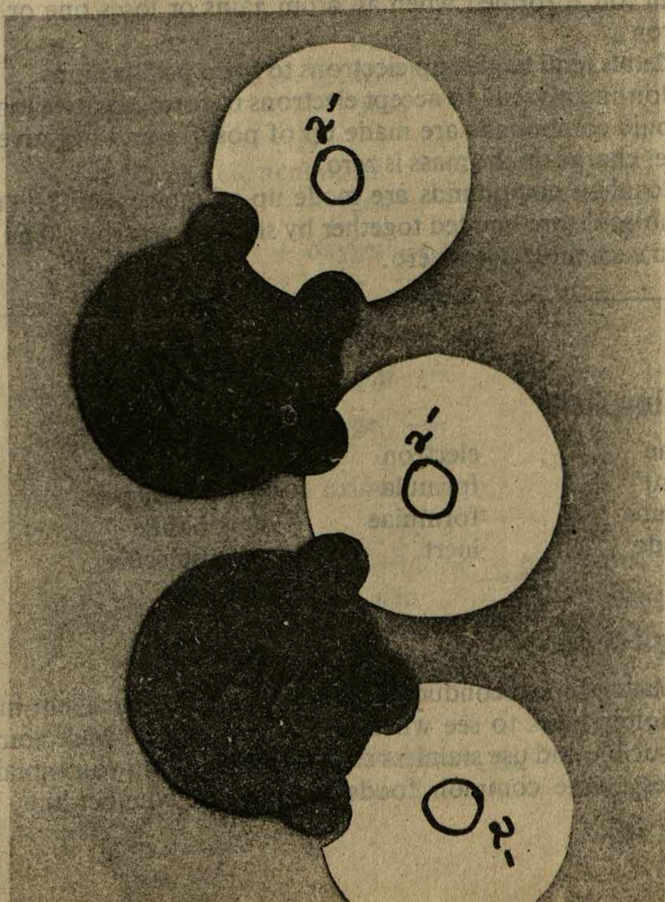
**Each group will need:**

- pieces of red and blue cardboard
- pair of scissors
- compass
- pencil

**What to do**

- Refer to table 23.3 (page 253) and figure 23.9.

**Figure 23.9:** Using models of ions to make up ionic formulae.



- Draw circles of 3 cm radius on the cardboard. Draw three circles for each ion in the list below. Use the red cardboard for the positive ions and the blue for the negative ions.
- Using your compass make marks 3 cm apart on the circumference of each circle you have drawn.
- Draw knobs on the red circles corresponding to the valency of the ion each circle is to represent. Draw holes on the blue circles.
- Cut out the outline of each ion you have drawn.
- Fit blues and reds together to make formulae for the following compounds: sodium nitrate, potassium sulphate, silver phosphate, copper chloride, aluminium phosphate, magnesium hydroxide, zinc sulphate.
- Write the formulae in your workbook.

## Chemical bonding

- Chemical bonding takes place between atoms.
- Each atom has a positive nucleus surrounded by a cloud of revolving electrons.
- The electrons revolve around the nucleus in shells.
- An ion is formed when an atom gains or loses one or more electrons.
- Metals tend to give up electrons to form positive ions.
- Non-metals tend to accept electrons to form negative ions.
- Ionic compounds are made up of positive and negative ions. The net charge on the mass is zero.
- Covalent compounds are made up of molecules. The atoms in a molecule are bonded together by sharing electrons. The net charge on each molecule is zero.

## Spelling list

chlorine
covalent
distribute
electrode
electron
formula
formulae
inert
ion
kilometre
mobile
molecule
nucleus
orbit
valency
vigorous

## Things to do

23.1 Glass will not conduct electricity — it is an excellent insulator. Test molten glass to see whether it still insulates. Melt some in a metal crucible and use stainless steel electrodes. Can you explain the result?

23.2 Test some common foods to find out whether they are ionic or molecular. They should be tested in the liquid state, either by melting them or dissolving them in water. Foods that could be tested are sugar, milk, butter, margarine, coffee, cooking oil, vinegar, bicarbonate of soda, honey and fat.

## More questions

Questions 23.3 to 23.7 deal with five types of chemical reactions. One complete equation is given for each type. Copy the remaining incomplete equations into your workbook and complete them (including writing the equation in formulae). (See appendix 1 for answers.)

**23.3** Metal and dilute acid.

**metal + acid → salt + hydrogen**

(a) sodium + dilute hydrochloric acid → sodium chloride + hydrogen

$2Na + 2HCl \rightarrow 2NaCl + H_2$

(b) magnesium + dilute hydrochloric acid →

(c) aluminium + dilute hydrochloric acid →

**23.4** Burning an element in air.

**element + oxygen → oxide**

(a) sodium + oxygen → sodium oxide

$4Na + O_2 \rightarrow 2Na_2O$

(b) copper + oxygen →

(c) aluminium + oxygen →

(d) carbon + oxygen →

**23.5** An acid and a basic oxide.

**basic oxide + acid → salt + water**

(a) potassium oxide + hydrochloric acid → potassium chloride + water

$K_2O + 2HCl \rightarrow 2KCl + H_2O$

(b) zinc oxide + hydrochloric acid →

(c) aluminium oxide + hydrochloric acid →

23.6 Neutralization.

**alkali** + **acid** → **salt** + **water**

(a) sodium hydroxide + hydrochloric acid → sodium chloride + water

$NaOH + HCl \rightarrow NaCl + H_2O$

(b) potassium hydroxide + sulphuric acid →

(c) calcium hydroxide + hydrochloric acid →

23.7 Acid and a carbonate.

**carbonate** + **acid** → **salt** + **carbon dioxide** + **water**

(a) sodium carbonate + sulphuric acid → sodium sulphate + carbon dioxide + water

$Na_2CO_3 + H_2SO_4 \rightarrow Na_2SO_4 + CO_2 + H_2O$

(b) copper carbonate + hydrochloric acid →

(c) aluminium carbonate + hydrochloric acid →

(d) aluminium carbonate + sulphuric acid →

## Test yourself (chapter 23)

Write the answers to questions 1 to 5 in your workbook.

1. Name a particle found in the nuclei of all atoms.
2. Name two types of chemical bonding.
3. Write down the formula for the copper ion.
4. What is the valency of the sulphate ion?
5. If $Na^+Cl^-$ is the ionic formula for sodium chloride, what is the ionic formula for sodium sulphate?

Choose the best answer to each of questions 6 to 10 and write its letter in your workbook.

6. The element whose atom is composed of only two particles is
   (a) hydrogen
   (b) helium
   (c) calcium
   (d) oxygen.

7. A positive ion is formed when an atom
   (a) gains electrons
   (b) loses electrons
   (c) shares electrons
   (d) moves towards a positive electrode.
8. The atoms in molecules are held together by
   (a) sharing electrons
   (b) sharing protons
   (c) transferring electrons from one atom to another
   (d) transferring protons from one atom to another.
9. Which of the following statements best explains the fact that neon does not react with other substances?
   (a) It is inert.
   (b) Its atoms are electrically neutral.
   (c) Its atoms have 8 electrons in the outer shell.
   (d) The nuclei of its atoms contain equal numbers of protons and neutrons.
10. The formula for magnesium chloride is $MgCl_2$. This formula is correct because
   (a) The charge on a chloride ion is double the charge on a magnesium ion.
   (b) The charge on the chloride ion is equal to the charge on a magnesium ion.
   (c) The charge on a magnesium ion is double the charge on a chloride ion.
   (d) The net charge on each ion is zero.

# Appendix 1: answers to selected questions

**1.9** Stars in the south would circle the South Celestial Pole once in 24 hours. It would be impossible to photograph this because the sky would be in sunlight for about half that time.

**15.33** 2 kgf/cm$^2$

**16.10** (a) 1.5 cm
(b) 0.67 kg

**18.18** 3.3 m, 9 compressions

**20.20** (a) The resistance would be halved.
(b) The resistance would be halved.
(c) Because the resistance is halved, a heavier current would flow through the jug. This would cause the water to boil more quickly.

**20.21** If the lights are connected in series, the removal of one of them will break the circuit and all the remaining lights will be extinguished. If they are connected in parallel, the removal of one will have no effect on the others.

**23.3** (b) magnesium + dilute hydrochloric acid → magnesium chloride + hydrogen

$$Mg + 2HCl \rightarrow MgCl_2 + H_2$$

(c) aluminium + dilute hydrochloric acid → aluminium chloride + hydrogen

$$2Al + 6HCl \rightarrow 2AlCl_3 + 3H_2$$

**23.4** (b) copper + oxygen → copper oxide

$$2Cu + O_2 \rightarrow 2CuO$$

(c) aluminium + oxygen → aluminium oxide

$$4Al + 3O_2 \rightarrow 2Al_2O_3$$

(d) carbon + oxygen → carbon dioxide

$C + O_2 \rightarrow CO_2$

**23.5** (b) zinc oxide + hydrochloric acid → zinc chloride + water

$ZnO + 2HCl \rightarrow ZnCl_2 + H_2O$

(c) aluminium oxide + hydrochloric acid → aluminium chloride + water

$Al_2O_3 + 6HCl \rightarrow 2AlCl_3 + 3H_2O$

**23.6** (b) potassium hydroxide + sulphuric acid → potassium sulphate + water

$2KOH + H_2SO_4 \rightarrow K_2SO_4 + 2H_2O$

(c) calcium hydroxide + hydrochloric acid → calcium chloride + water

$Ca(OH)_2 + 2HCl \rightarrow CaCl_2 + 2H_2O$

**23.7** (b) copper carbonate + hydrochloric acid → copper chloride + carbon dioxide + water

$CuCO_3 + 2HCl \rightarrow CuCl_2 + CO_2 + H_2O$

(c) aluminium carbonate + hydrochloric acid → aluminium chloride + carbon dioxide + water

$Al_2(CO_3)_3 + 6HCl \rightarrow 2AlCl_3 + 3CO_2 + 3H_2O$

(d) aluminium carbonate + sulphuric acid → aluminium sulphate + carbon dioxide + water

$Al_2(CO_3)_3 \quad 3H_2SO_4 \rightarrow Al_2(SO_4)_3 + 3CO_2 + 3H_2O$

# Appendix 2: answers to tests

**Chapter 1**

1. (c)
2. (b)
3. (a)

**Chapter 2**

1. aluminium, silicon and oxygen
2. occurrence of day and night
3. occurrence of the seasons
4. (a) Hours of daylight are shorter. (b) Sun's rays strike the earth more obliquely.
5. one year
6. (b) (Note that the sun rising in the east could be due to the revolution of the sun around the earth.)
7. (c)
8. (b)
9. (c)

**Chapter 3**

1. capillaries
2. lung
3. veins
4. white cells
5. haemoglobin
6. (b)
7. (b)
8. (b)
9. (a)
10. (d)

**Chapter 4**

1. skin, lungs, kidneys
2. carbon dioxide and water
3. urea and water
4. water, salts, urea and traces of carbon dioxide
5. (c)
6. (b)
7. (b)
8. (c)
9. (c)

**Chapter 5**

1. copper
2. air
3. black
4. black
5. silvery
6. (c)
7. (c)
8. (d)
9. (b)

**Chapter 6**

1. carbon
2. calcium oxide
3. sulphur dioxide
4. brass
5. copper oxide
6. (b)
7. (b)
8. (d)
9. (b)
10. (c)
11. (c)

**Chapter 7**

1. an acid
2. hydrochloric, nitric and sulphuric acids
3. nickel oxide and nitric acid, or nickel carbonate and nitric acid
4. **(a)** sodium chloride
   **(b)** potassium chloride
   **(c)** calcium chloride
   **(d)** sodium nitrate
   **(e)** potassium nitrate
   **(f)** calcium nitrate
   **(g)** sodium sulphate
   **(h)** potassium sulphate
   **(i)** calcium sulphate
5. (a)
6. (b)
7. (a)

**Chapter 8**

1. proton, neutron and electron
2. electrons
3. attract
4. (b)
5. (c)

**Chapter 9**

1. potassium nitrate
2. cathode
3. sugar
4. potassium nitrate
5. cathode
6. (d)
7. (a)
8. (b)

**Chapter 10**

1. **(a)** levees
   **(b)** upper tract
   **(c)** gibber plain
   **(d)** raised rock platform
   **(e)** raised sea level
   **(f)** middle tract
   **(g)** raised sea level
2. (c)
3. (b)
4. (b)
5. (c)

**Chapter 11**

1. **(a)** quartz
   **(b)** calcite
   **(c)** mud
   **(d)** carbon dioxide

**(e)** conglomerate
**(f)** calcite
2. **(a)** sedimentary rock
   **(b)** sediments
   **(c)** rock fragments
3. (b)
4. (a)
5. (d)
6. (a)

### Chapter 12
1. coal
2. silica
3. Mesozoic
4. (b)
5. (c)
6. (b)
7. (c)
8. (c)
9. (d)

### Chapter 13
1. kilogram force
2. gravity and friction
3. (b)
4. (d)
5. (b)

### Chapter 14
1. **(a)** sawdust
   **(b)** lead
   **(c)** sawdust
2. **(a)** iron
   **(b)** kerosene
3. 8 g/cm$^3$
4. (c)
5. (d)

### Chapter 15
1. (b)
2. (c)
3. (a)
4. (c)
5. (a)
6. (c)
7. (b)

### Chapter 16
1. 20 kg
2. 66 cm
3. (b)

### Chapter 17
1. **(a)** A
   **(b)** B
   **(c)** B
   **(d)** B
2. **(a)** 3 per second
   **(b)** 10 cm

### Chapter 18
1. compression, or longitudinal, wave
2. reflection
3. inner ear
4. amplitude
5. slower
6. 0.5 m
7. lips
8. longer
9. (a)
10. (d)
11. (b)
12. (c)

### Chapter 19
1. (c)
2. (d)
3. (a)
4. (d)
5. Author chooses either B or D. However, B would probably be better because it is simpler and could therefore be identified at a greater distance.

### Chapter 20
1. chemical energy
2. **(a)** electrons
   **(b)** protons
3. **(a)** conductor
   **(b)** insulator
4. volts
5. amps
6. less
7. better
8. heat
9. (b)
10. (d)
11. (b)
12. (b)
13. (c)
14. (a)

### Chapter 21
1. magnesium, aluminium or zinc
2. tin, lead or copper
3. gold
4. (b)
5. (c)
6. (a)
7. (c)
8. (a)

### Chapter 22
1. potassium, sodium, calcium (any metal above copper in the series)
2. gold
3. **(a)** haematite
   **(b)** bauxite
4. coke and limestone
5. tin
6. (a)
7. (b)
8. (c)
9. (c)
10. (c)
11. (b)

### Chapter 23
1. proton
2. ionic and covalent
3. $Cu^{2+}$
4. $-2$
5. $(Na^+)_2(SO_4)^{2-}$
6. (a)
7. (b)
8. (a)
9. (c)
10. (c)

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